DEVELOPMENT OF LIQUEFACTION SUSCEPTIBILITY AND HAZARD MAPS FOR THE ISLANDS OF JAMAICA AND TRINIDAD

A Thesis
Presented to
The Academic Faculty

by

Jason Edmund Kraft

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in the
School of Civil and Environmental Engineering

Georgia Institute of Technology

May 2013

DEVELOPMENT OF LIQUEFACTION SUSCEPTIBILITY AND HAZARD MAPS FOR THE ISLANDS OF JAMAICA AND TRINIDAD

Approved by:

Dr. Glenn Rix, Committee Chairman
Associate Chair of Administration and Finance,
School of Civil and Environmental Engineering
Georgia Institute of Technology

Dr. Reginald DesRoches
Karen and John Huff School Chair, School
of Civil and Environmental Engineering
Georgia Institute of Technology

Dr. Kimberly Kurtis
Professor, School of Civil and
Environmental Engineering
Georgia Institute of Technology

Date Approved: April 4, 2013

To my family, whose support for my work has never waivered.

ACKNOWLEDGEMENTS

I wish to thank Dr. Glenn Rix, Professor and Associate Chair of the School of Civil and Environmental Engineering for his help in developing my thesis topic, his support, and his continual advice and expertise throughout the process, and for sharing his experiences and inspiring me to follow this path. I look forward to returning to share my own experiences in the coming years.

I would also like to thank the other members of my committee, Dr. Reginald DesRoches and Dr. Kimberly Kurtis, for their time, efforts, and advice not only during the review but also on our research trips together. I would also like to thank Dr. French for inviting me to accompany him on several of his visits with GIS experts, where I gained useful information that I was able to use in this study. The insight I have been able to gather from all of you has made me a better engineer and will be applied again and again in the future.

Thank you to all members of the CHAMP project for sharing your knowledge, expertise, and skills. Our diverse group made our travels extremely informative and valuable. I would like to thank Thomas Douthat and Joy Zhou for taking their time to share the data with me that made this work possible.

I would like to thank the University of the West Indies campuses in Mona, Jamaica and in St. Augustine, Trinidad for the data, knowledge, and hospitality they shared during our visits. Thank you to the University of the West Indies Department of Geomatics Engineering and Land Management and the Food and Agriculture Organization of the United Nations for providing the data for this study.

Thank you especially to the Speedwell Foundation. Your generosity gave me the ability to pursue my dreams at Georgia Tech.

Thank you also to the Georgia Tech Police Department and, in particular, Andy, Jennifer, Will, and Frank of the Office of Emergency Preparedness. Working with you has given me invaluable experience and knowledge in dealing with emergencies, and your universal encouragement and support throughout my most recent years at Georgia Tech will never be forgotten.

Finally, none of my work would be possible without the support of my friends and family. Thank you for your patience, your support, and for believing in my work and my potential. To my sister Amanda, thank you for the laughs, the sympathy, and the advice you have offered. To my parents, Ed and Linda, thank you for being a constant inspiration and showing me the impact that a sound mind and hard work can have. It is because of you that I have already been able to do more than I could have possibly imagined and why I have so much to look forward to in the future.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Caribbean nations lie within a zone of distinct seismic hazard. While ground motion in the region has been analyzed, the potential for liquefaction has not been evaluated in most cases. In order to evaluate liquefaction, data describing soil composition, surficial geology, and seismic hazard analyses were collected and applied. This allowed for expansion of previously localized liquefaction analysis to be expanded to the extents of two island nations in the Caribbean.

This thesis utilizes the Youd and Perkins (1978) qualitative liquefaction susceptibility and Holzer et al. (2011) liquefaction probability methodologies to evaluate the possibility of liquefaction in Trinidad and Jamaica during major seismic events. Maps were developed using geographic information system (GIS) data to compare susceptibility and hazard across the islands at varying levels of magnitude. In this way, the distribution of liquefiable deposits is displayed in a manner that can be used quickly and easily to motivate further study of susceptible regions and mitigation activities to reduce the risk posed by liquefaction in the countries.

CHAPTER 1: INTRODUCTION

1.1 Motivation for Study

The Caribbean, although well recognized for its perennial climatological threat from hurricanes and other tropical storms, was not until recently considered by the general public to be affected by significant seismic activity, despite several historical instances of extremely strong earthquakes. The 12 January 2010 7.0 M_W earthquake that occurred in direct proximity to Port-au-Prince, Haiti, caused massive devastation due to ground motion and ground failure compounded by high population density and lack of engineered and regulated construction practices. Following these events, there was an immediate demand from local government, non-governmental organizations, and regional engineers for data and code provisions to address the seismic hazard present throughout the Caribbean. These resources have largely been provided for with ground shaking and spectral acceleration values for critical infrastructure and general construction design to resist the earthquake hazard (Shedlock, 1999; Bozzoni, et al., 2011). While adherence to building codes and other provisions varies between and within Caribbean countries, these codes will prove to increase survivability during seismic events. The new building codes and parameters do not, however, directly address the threat of liquefaction, which has potential for more severe long-term implications during the response and recovery phases of a seismic event.

1.1.1 Importance of Liquefaction Study and Consideration

Ground shaking is the more generally publicized hazard associated with earthquakes due to its immediate and obvious effects, primarily the collapse of inadequately designed structures. The effects of liquefaction can be as severe and costly, if not more so when compared to ground motion, even if they are not immediately detectable. Liquefaction has the potential to not only cause damage, but also to compound the effects of ground shaking by removing necessary resource pathways and disabling critical infrastructure, including those essential to government and business operations, exploiting primary “vulnerabilities” during the crisis period (Lindell & Prater, 2003; Sumer, et al., 2007). This weakness is amplified in island nations such as those of the Caribbean, where the economy and supply chain survive based on the import and export of goods through ports, which are particularly susceptible to damage from liquefaction due to their proximity to alluvial deposits and water and their use of engineered and non-engineered fill material, each factors which played a major role in Haiti (Sumer, et al., 2007; Werner, et al., 2011; Green, et al., 2011).

Liquefaction effects resulting from the 2010 Haiti earthquake caused damage disabling the primary port in Port-au-Prince which immediately limited the ability of foreign aid to reach the country. This included damage to both port storage and machinery largely due to its construction on presumably poorly-engineered sandy fill material. The ramifications of this delay were felt immediately due to the limitations of available emergency supplies following the earthquake resulting from building collapse due to ground shaking, as the small stockpiles could not be resupplied in short order. Significant damage was caused by liquefaction elsewhere which, in addition to the disabled port equipment, limited emergency access due to slope and bridge failures on primary roads in the area of the earthquake. Liquefaction occurred at numerous sites along the Haiti coastline besides Port-au-Prince as shown in Figure 1.1, with effects ranging from minor settlement to building failure and total beach collapse (Olson, et al., 2011; Green, et al., 2011).

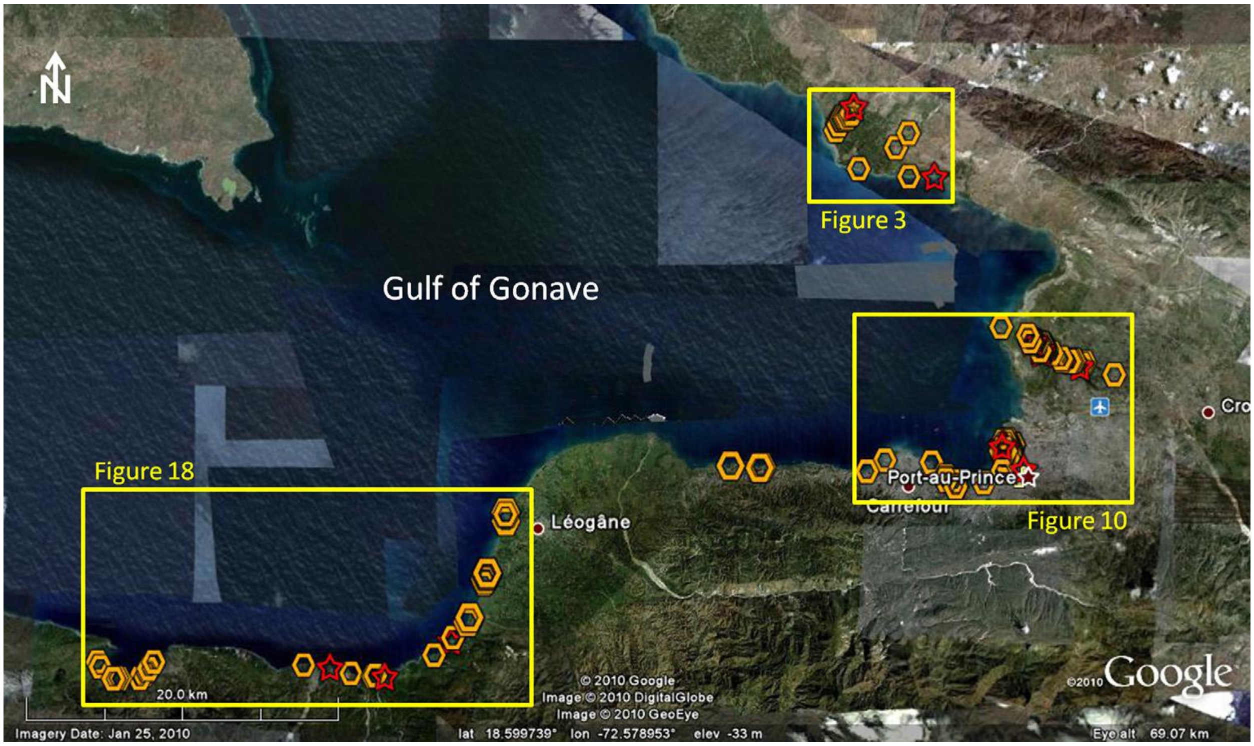

Figure 1.1 - Locations of liquefaction related ground failure following Haiti 2010 earthquake (images courtesy Google Earth, 2010) (Olson, et al., 2011)

1.1.2 Improvement of Practices and Knowledge with Regard to Mitigation

Historical seismic evaluation and Probabilistic Seismic Hazard Analyses (PSHAs) have been performed for the region, both preceding and following the 2010 earthquake. These studies include considerations of historical seismic activity, proximity to fault lines, and recorded attenuation, and provide estimates of expected ground acceleration for use in load calculations and are examined in Chapter 2 (Bozzoni, et al., 2011; Calais, et al., 1992; Shedlock, 1999). These values are used in particular for essential structures, including public safety, medical, and commerce construction. The International Building Code (IBC) is also being adopted more widely, although with varying enforcement across the region. Large portions of the building stock remain well below the code provisions, but the majority of these are residential dwellings beyond the control of the building code. In addition, local universities and governments are producing global positioning system (GPS) studies and new profiling data for a more accurate estimation of the seismic threat (DeMets & Wiggins-Grandison, 2007; Hornbach, 2011).

These guidelines do not, however, include guidelines identifying areas of high liquefaction hazard. The code issued by the Association of Caribbean States addresses only that a site should be evaluated through shear velocity or other in-situ testing for liquefaction hazard before construction (Faccioli & Calvi, 2003; Adams, 1997). This fails to address the information necessary for mitigation of hazards and for the identification of the most vulnerable areas during response following a major earthquake. The first potential action for mitigation of a hazard, as listed by FEMA, is prevention of impact by avoiding the hazard where possible (Federal Emergency Management Agency, 2003). By providing a geographic display of hazard distribution, additional resources are provided for citizens and businesses to develop a more resilient community through mitigation action and well-informed planning activities.

1.2 Scope of Thesis

This thesis presents geographic information system (GIS) soil surveys for Jamaica and Trinidad with the addition of liquefaction hazard data using two methods for representation of the hazard of liquefaction due to earthquakes. Following travel to the countries in question, the information developed will be able to serve as a resource for consideration of future seismic events.

The second chapter addresses the mechanics of liquefaction and the current understanding of various soil and geologic parameters and their impact on the susceptibility of a soil deposit to liquefy. Also reviewed is the process used for developing Probabilistic Seismic Hazard Assessments (PSHAs) and their purpose in hazard mapping.

The third chapter reviews the data collected and evaluated for each of the two countries studied. Data and descriptions were collected from a wide array of sources, including current PSHAs, recent soil surveys, and historical records.

Chapter 4 examines the process of qualitative liquefaction hazard assignment using soil survey data and categories established by Youd and Perkins (1978). The advantages and disadvantages of high and low resolution GIS data were also noted.

Methodology by which the probabilistic assessments were conducted is presented in Chapter 5. These processes integrated geologic classification, ground motion parameters, and liquefaction probabilities to develop a magnitude related series of hazard maps for each of the countries.

Conclusions on the hazard conditions of each island and the processes presented are present in Chapter 6. Guidelines and recommendations for use of the hazard maps were also established in this section, as well as potential expansion of research in the area of liquefaction hazard analysis.

CHAPTER 2: CURRENT UNDERSTANDING

2.1 Introduction

Liquefaction is among other ground failure conditions such as slope failure and bearing capacity but is less common to evaluate for during design with the exception of dynamically loaded systems and for areas of known seismic hazard. Design needs for liquefaction hazards are often best understood by engineers local to the area and who have witnessed soil behavior during earthquake events with strong ground motion, which has not occurred on the islands in many years. Evaluating liquefaction is performed through in-situ testing following earthquakes to determine depth and extent, but some of the same techniques can be applied before an event takes place (Olson, et al., 2011). Analysis of the hazard and susceptibility associated with a soil deposit requires knowledge of the geologic setting, soil composition, and the earthquake hazard in the area. Earthquake hazard is determined using probabilistic methods and historical analysis of all faults affecting the given location. This chapter reviews the methods used for evaluation and testing of liquefaction hazard.

2.2 Previous Research on Liquefaction

Liquefaction and its sources have been extensively researched due to the hazard it poses to marine and other structures near the ground water table, particularly in seismically active regions. Failure can occur under rapid static loading as well as dynamic loading, but dynamic reaction to seismic loading is the primary focus of hazard study. Correlations have also been performed to connect liquefaction hazard with in-situ site exploration using various test methodologies.

2.2.1 Causes of Liquefaction

Liquefaction is a mechanism of failure that occurs when substantial loading induces pore pressures in a soil deposit that reduce the effective stress to a point that the soil does not retain shear strength (Youd, et al., 2001). This can occur in-situ, leading to settlement within the layer and of the layers above the deposit, but pore pressure sometimes induces an upward force, due to increased pore fluid pressure, to the point that the soil particles are ejected at the ground surface, leaving visible evidence of the liquefaction known as a sand boil (Tsukamoto & Ishihara, 2010). Sand boils, as shown in Figure 2.5, are well documented during historical strong events due to the visual spectacle (Elliot, 1892). In addition, the decrease in shear strength induces severe and rapid settlement under surface loads that can cause significant and extensive damage to structures on the ground surface, mainly resulting from differential settlement (Youd, et al., 2001). Liquefaction primarily results from a dynamic load and is generally recognized in relationship to earthquakes, but can also be caused by manmade dynamic loads or by wave action in beach sediments (Seed H. , 1987).

Liquefaction effects increased with intensity and duration of earthquake loading. High peaks of short duration are unlikely to produce liquefaction, as multiple cycles of shear strain are required to induce overall stresses capable of liquefying soil. Seismic demand is generally described as a ratio of induced shear force to effective stress at depth, often referred to as cyclic stress ratio (CSR) (Youd, et al., 2001). This is reflected by the Youd and Idriss (2001) application of moment magnitude for application to probabilistic expression of liquefaction, as duration is more accurately reflected by a magnitude parameter than in a single identified spike of peak acceleration. Correlations have been used to identify magnitude scaling factors (MSF) to relate the magnitude to shear effects (Seed, et al., 1985). The effects of magnitude variation with a given acceleration value are shown by Figure 2.1 as magnitude, and therefore MSF (constant with a given magnitude) vary. This is also reflected in the changes in the liquefaction probability maps for Trinidad and Jamaica with variation of magnitude produced in this report.

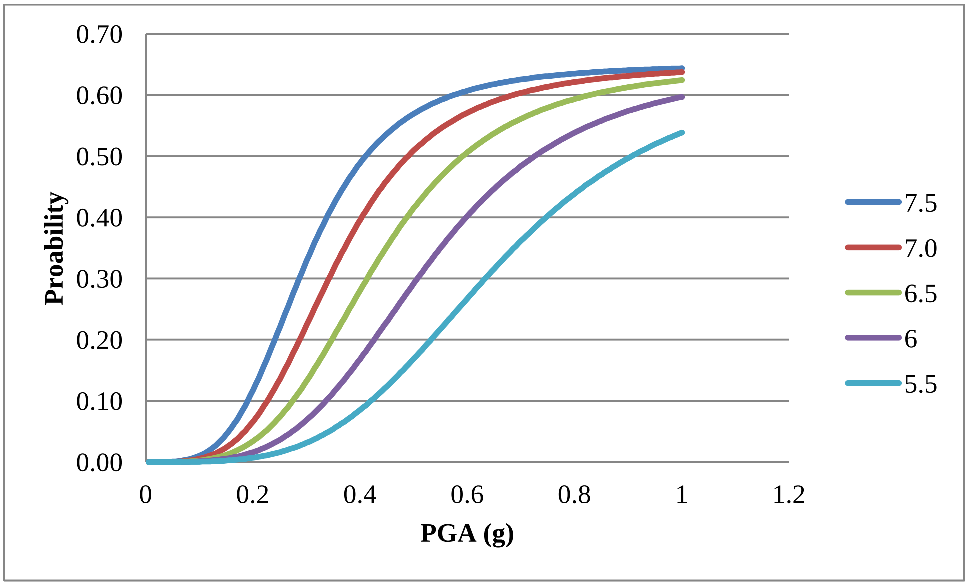

Figure 2.1 - Liquefaction probability versus PGA for varying magnitudes in Alluvial Fan

2.2.2 Soil Composition Effects

The rapid decrease of effective stress causing liquefaction necessitates a granular media dominated by sand size particles in order for pore fluid to adequately travel and affect particle interaction. This tendency is mentioned by Youd et al. (2001) as increasing fines content applies an increasing factor for N-value, and Sumer et al. (2007) identified qualitative relationships between grain size distribution and potential for liquefaction in marine sediments, where liquefaction tends to be a greater hazard due to both the nature of soils in these sandy geologies and the proximity to groundwater. This relationship is shown in Figure 2.2. Increased pore pressure induces decreased effective stress which reduces friction between the particles and has a much greater effect in the particle interactions of coarse grained soils. As a result, looser packing arrangements are more vulnerable to liquefaction due to lesser particle contact area, and thus less friction to resist shear. Also noted is the fact that water (or other pore fluid) must be present or directly in proximity in order to induce pore pressure for liquefaction to occur. (Youd & Perkins, 1978) It should be noted that recent studies have shown that due to large shear displacement and the layered soil structure, there is a potential for liquefaction even in soils with significant (>15%) fines content due to soil stratification and segregated coarse soil materials (Bray & Sancio, 2006; Toprak & Holzer, 2003; Kayen & Mitchell, 1997).

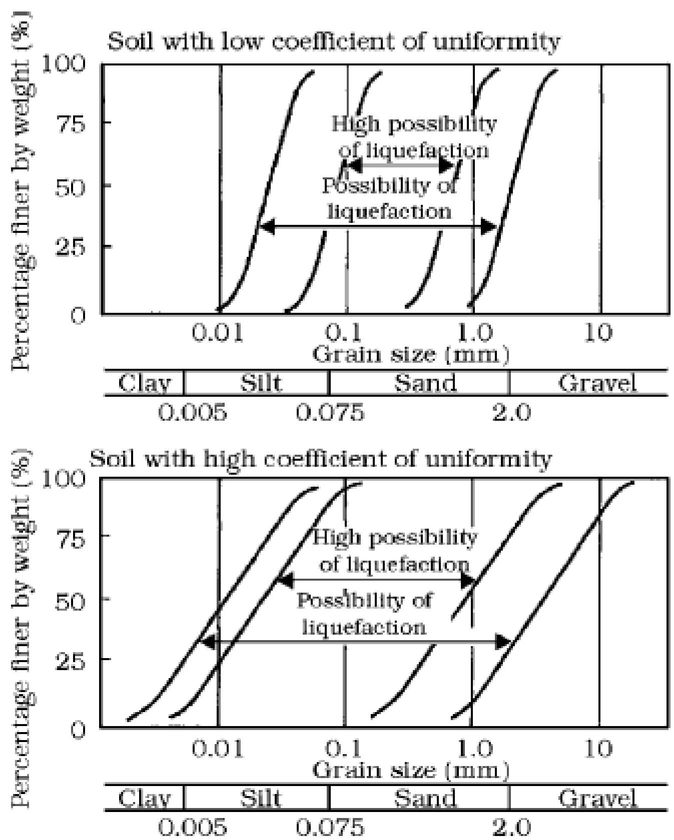

Figure 2.2 - Qualitative relationship of liquefaction susceptibility with grain size distribution (Sumer, et al., 2007)

2.2.3 Geologic Structure Effects

Soil placement has significant effects on liquefaction susceptibility. As noted in the discussion of soil composition relationship with liquefaction, a loose packing enhances liquefaction porewater pressure effect. Liquefaction is therefore much more prevalent in alluvial and marine deposits, both of which combine soils with low relative densities and a water table in direct proximity to the surface. The highly stratified nature of alluvial deposits also creates the potential for amplitude of ground displacements to exceed the depth of sand and silty or clayey layers. During the liquefaction process, this would allow porewater and liquefied material to pass through layers of low hydraulic conductivity, transferring stress expanding the liquefied region where it could have been limited by the less permeable layers (Kayen & Mitchell, 1997). Liquefaction has, in numerous cases, been observed in sediments including strata of low plasticity silts and clays (Beroya & Aydin, 2010; Olson, et al., 2011). High plasticity silts and clays are generally considered non-liquefiable deposits.

The most effective means of determining liquefaction hazard is study of the soil deposit using dynamic in-situ testing. The nature of liquefiable deposits makes undisturbed sampling difficult due to high sand content, often requiring the use of in-situ testing, such as standard penetrometer (SPT) testing, seismic cone penetrometer testing, or other geophysical methods (Liao & Mayne, 2002; Beroya, et al., 2009; Seed, et al., 1985; Youd, et al., 2001). Particularly in the case of CPT, the exact extents of liquefiable soil strata can be determined, allowing for calculation of more complex liquefaction susceptibility estimates, including the Youd and Perkins (1987) Liquefaction Severity Index and the Toprak and Holzer (2003) Liquefaction Potential Index, both of which incorporate liquefiable layer thickness and proximity of liquefiable layers to the ground surface. Youd et al. (2001) also provides relationships between cyclic shear resistance and cone tip resistance. Unfortunately, there is not an extensive database for cone or boring data in either of the countries considered in this study. That which has been performed provides data overwhelmingly in urban centers of the countries, which have been mostly overlain by fill material which is more susceptible to liquefaction than many natural surficial deposits. What data is available is most likely in the form of SPT values, for which Seed et al. (1985) provided threshold values shown in Figure 2.3 for a 7.5M earthquake.

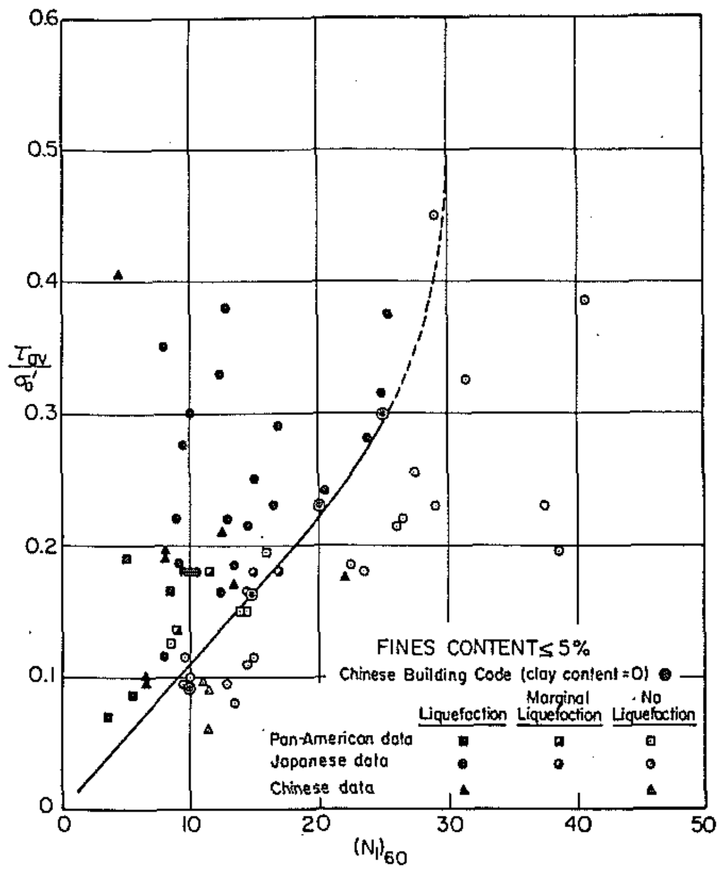

Figure 2.3 - Stress ratio versus normalized $(N_1)_{60}$ (Seed, et al., 1985)

2.3 Mapping of Seismic Hazards

Efforts to map seismic hazard are performed based on identified and researched faults and other seismic sources such as volcanoes. The complex nature of Caribbean faulting for both of the two islands requires analysis of several plates as well as intraplate faulting that could induce ground shaking capable of producing liquefaction.

2.3.1 Probabilistic Seismic Hazard Analysis

Probabilistic seismic hazard analyses are the standard for evaluation of the seismic systems impacting a location. The process is described in detail with examples and a variety of probabilistic models by McGuire and Arabasz (1990). The analyses begin with historical studies of earthquakes caused by faults or seismic zones. These studies provide for determination of maximum and characteristic magnitudes of earthquakes produced by a seismic system as well as intervals and distribution of event magnitude. This information is used to develop a series of probabilities, including probabilities for distance from a given location where a rupture will occur, the magnitude of a given earthquake, and the likelihood of such an earthquake to induce ground shaking above a designated value at that site and magnitude combination. The probability of ground motion exceedance can be determined using a weighted variety of both site specific and general models to provide a more accurate overall probability for a given ground motion and location (McGuire & Arabasz, 1990). Applying these probability values for numerous combinations of distances and magnitudes can be used to develop a hazard curve presenting rate of exceedance versus values of a ground motion parameter. By calculating these curves for a large number of locations, seismic hazard maps can be developed, which describe general acceleration values for larger areas and are more directly applied for selection of design values for building codes.

Bozzoni et al. (2011) developed a seismic hazard map for the eastern Caribbean determining peak ground acceleration (PGA) for a 475 year return period. This was an update of a previously developed map by Shepherd et al. (1997) from which the Jamaica acceleration values were used, but which was a much lower resolution and less delineated in the Lesser Antilles than the updated version, as only two acceleration values were provided. A similar example was provided in 1999 from the United States Geological Survey (Shedlock, 1999). The range of the updated PSHA included the Lesser Antilles, beginning in Anguilla and continuing to Trinidad. In particular, Trinidad is examined due to its higher population and more significant economic role. Also, as it is much larger than any of the other islands along the eastern Caribbean border, it is the only one to be characterized by a significant range of hazard levels.

2.3.2 Previous Methods of Liquefaction Susceptibility Mapping

Preceding the use of GIS, liquefaction maps were hand drawn following extensive study of geology, soil types, and seismic hazard. Youd and Perkins (1978) utilized two sets of data to develop descriptions of liquefaction susceptibility. This allows for consideration of liquefaction hazard over both large and small regions though examination of soil type, age, and geology, values commonly available through soil survey or soil survey data throughout the world. Hengesh and Bachuber (2005) employed a flow chart based methodology employing predicted ground motion and a well defined soil survey of the city of San Juan. This very focused survey also allowed inclusion of data beyond the normally required values including groundwater contours and soil boring logs. It did not reach beyond the limits of the city, which had been thoroughly surveyed by necessity for construction. A similar process was applied recently in the Philippines, where similar surficial geology and seismic setting allow for some comparison with the values for Jamaica and Trinidad (Beroya & Aydin, 2010). The liquefaction potential index is one of several developed values to identify and analyze liquefiable layers for well defined soil deposits with available data (Toprak & Holzer, 2003). Numerous test sites are needed to improve accuracy and reliability in these highly specific assessments, as noted by Baise et al. (2006) Testing must use a sample size capable of reducing uncertainty in spatial variability to a reasonable level.

GIS has previously been applied for development of hazard maps in the Caribbean in Mayaguez, Puerto Rico (Macari & Hoyos, 2005). However, in comparison to this study, the Mayaguez liquefaction survey was again very focused, using a much narrower range and much higher resolution data to determine the point by point hazard affecting the area. It incorporates similar data in comparison to the San Juan hazard map, but in a more digitized fashion. Procedures used in this thesis expand on the localized mapping process using GIS.

2.4 Seismic Setting and Key Historical Earthquakes

Historical assessment of fault activity is necessary for all types of hazard assessment. Consideration of the history of a disaster prone area can also offer insight into areas of higher risks and tendencies of geotechnical response to an event. Both islands have a history of serious earthquakes with significant damage to their capital cities, which are also population centers for the countries. The faults in the region are shown in Figure 2.4.

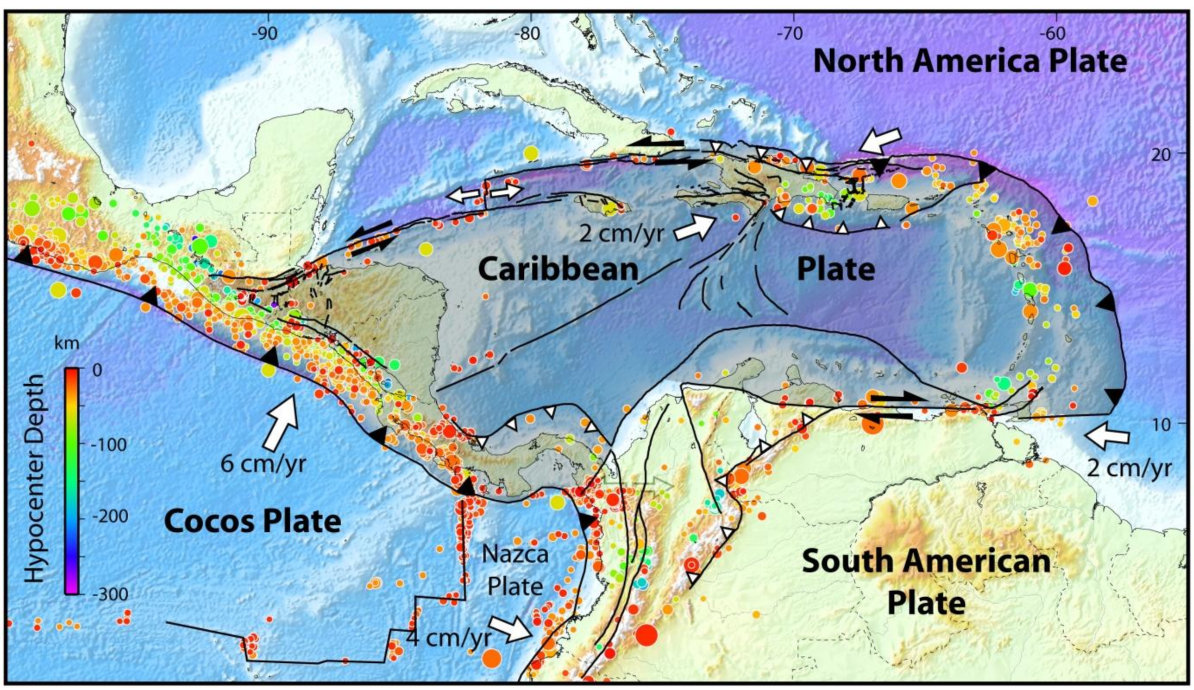

Figure 2.4 - Major faults of the Caribbean (Calais, 2013)

2.4.1 Jamaica

Jamaica's location is along the strike-slip fault between the Caribbean and North American plates, the same fault impacting Puerto Rico and Hispaniola, the Greater Antilles islands (Calais, et al, 1992). This is the primary seismic system impacting the island although earthquakes are known to be common on local faults on the island. The island lies on the Gonâve microplate, which is situated between the two larger plates. Tracking using GPS indicates that the plate moves relative to its neighbors at a rate of 15 mm/yr east relative to the North American plate and 5 mm/yr west relative to the Caribbean plate, with this motion being largely responsible for earthquakes on the island (DeMets & Wiggins-Grandison, 2007). Among the numerous faults on the island are the faults in the Blue Mountain region, just northeast of the capital city of Kingston, which meet with the Enriquillo Plaintain Garden fault, an extension of the same fault that caused the Haiti earthquake, which radar tomography has tracked as passing directly through the harbor of Kingston (Hornbach, 2011). This fault zone has the highest number of recent earthquakes according to seismic mapping, as shown in Figure 2.4.

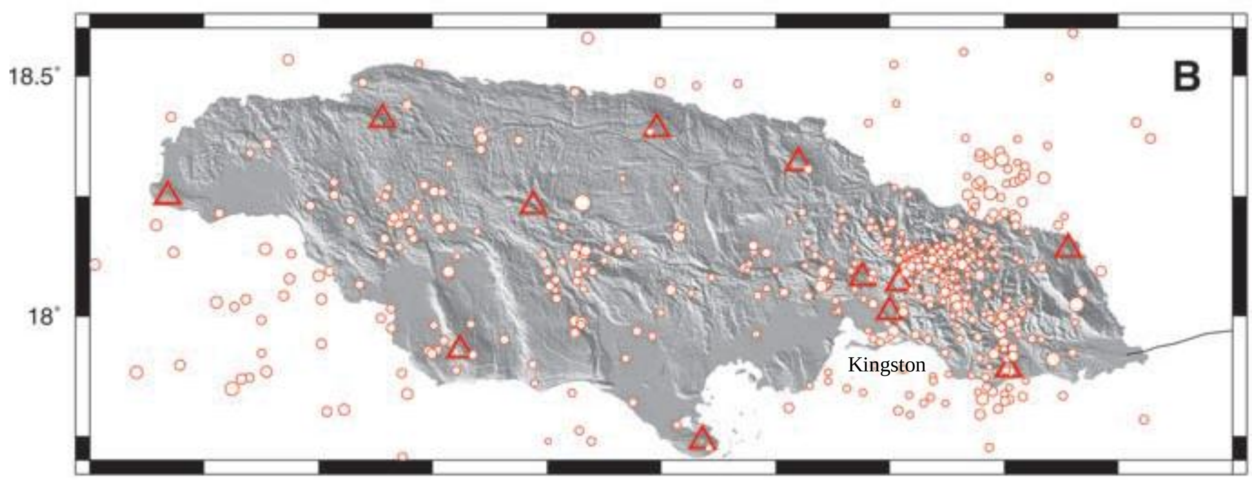

Figure 2.5 - Seismic activity on the island of Jamaica, 1998-2004 (circles), magnitude equal or greater than 2.0 (DeMets & Wiggins-Grandison, 2007)

Recent earthquakes have not been large in magnitude, but there exists a potential for an earthquake of M=7.2-7.3 given the GPS recorded strain values (DeMets & Wiggins-Grandison, 2007). There is also a well known historical earthquake, generally referred to as the Port Royal earthquake, which occurred in 1692 (Hornbach, 2011). During that earthquake, a substantial portion of the city of Port Royal, which once resided on the peninsula (referred to locally as a "spit") extending from Kingston, was subject to liquefaction and lateral spreading effects causing it to sink into the sea (Elliot, 1892; Tortello, 1692: Earthquake of Port Royal, 2013). Similar effects with greater damage to mainland Kingston were described with regard to a 1907 earthquake, shown in Figure 2.5 (Tortello, 2013). While the magnitude of these events cannot be reliably estimated, they make it clear that the seismic zones affecting Jamaica are easily capable of causing liquefaction inducing earthquakes. The potential for another instance of liquefaction in the area of Port Royal and Kingston is mentioned by Hornbach et al. (2011) as well.

Figure 2.6 - Liquefaction along fault, 1907 Kingston Earthquake (Brown C. W., 1907)

2.4.2 Trinidad

Trinidad is located at the intersection of the Caribbean, North American, and South American plates. This creates two fault conditions for the island, with the first being the subduction fault to the east, which is responsible for the formation of not only Trinidad but also the remainder of the Lesser Antilles, the string of active volcanic islands forming the eastern extent of the Caribbean Sea. The second fault is the east-west strike-slip fault between the Caribbean and South American plates, shown in Figure 2.4.

Due to the complexity of the two active faults, there is significant uncertainty with regard to the location of the intersection of the subduction and strike slip faults, known to be in the area to the west and south of Trinidad. The Caribbean plate has a velocity with respect to both faults to the east at a rate of 20 mm/yr (Weber, et al., 2012). Bozzoni et al. (2011) describes Trinidad as being affected by six seismic zones with variations of fault activity, mechanism, and characteristic earthquake depth. One of these zones includes the localized faults on the island itself, the Central Range and Northern Range Faults, which have an estimated maximum magnitude of 6.9 (Beard & Claire, 2012; Bozzoni, et al., 2011).

The faults impacting Trinidad have a well recorded history of strong ground motion, particularly the strike-slip fault, which in 1766 included an earthquake with an estimated magnitude between 6.5 and 7.5, although it has been suggested that the magnitude was significantly higher (Mocquet, 2007). That earthquake was recorded in Trinidad as causing landslides and significant damage to buildings in Port of Spain, including a fort and a church, generally regarded as the stronger structures of the time period (Mocquet, 2007). Magnitudes greater than 7.0 have been reached regularly in the eastern subduction zone as well, with significant events listed in 1888 and 1918 as well as the 1766 earthquake (Graham, 2010). The faults on the island itself, while active, generally reach lower magnitudes than those at plate intersections, but the decreased distance in comparison to the other faults results in similar strong ground motion characteristics. Recent strong earthquakes affecting Trinidad are shown in Figure 2.7.

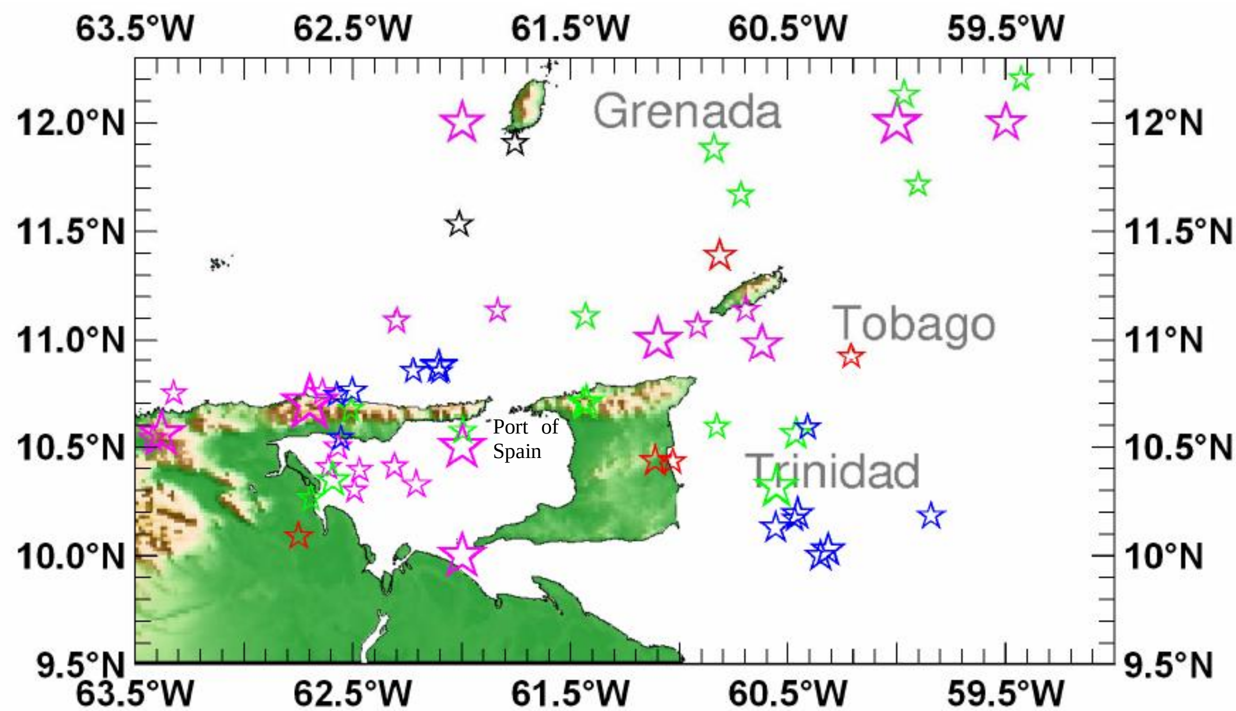

Figure 2.7 - Earthquakes greater than 5.0 M 1955-2008 (Latchman, 2010)

GPS motion studies have also been performed for the Caribbean and South American intersection, indicating motion of up to 13 mm/yr in Trinidad relative to the South American plate (Weber, et al., 2012). All of the faults affecting Trinidad are capable of creating an earthquake with the potential to induce liquefaction in vulnerable soil deposits.

2.5 Summary

Scientifically, liquefaction is a well understood mechanism. Using in-situ tests and soil parameters, the potential for occurrence can be relatively well predicted. However, the unique aspects of soil deposits require site testing at individual locations to determine the specific liquefaction potential.

Seismic hazard in the Caribbean and particularly for the islands in question has been researched extensively. Methods of analysis include historical research, probabilistic analysis, and GPS studies. This research provides valuable and accurate ground motion parameters for this thesis.

CHAPTER 3: DATA

3.1 Introduction

The accuracy and function of a GIS rely on extensive geodetically based datasets. In order to develop susceptibility and hazard maps, numerous data sources were combined to add the necessary parameters to the existing GIS databases. As necessary, other GIS layers and supplementary data were employed to resolve uncertainty about soil group classifications. Locally developed hazard maps for the country were also considered, particularly with identification of floodplains and extents of hazardous areas. Only through cross checking of multiple data sources could the choices made regarding geologic designations and assigned values be considered accurate and justified. ArcGIS was the software utilized for manipulation of GIS databases for this thesis.

3.2 Data Requirements

Data necessary for accurate representation of liquefaction susceptibility and hazard includes representations of both the soil profile of the country and seismic hazard affecting the country. First, in order to determine susceptibility, a description of the soil, including grain size and manner of placement, and approximate groundwater condition were required. Soil descriptions were evaluated using dominant soil codes for each parcel provided within the GIS data, while groundwater condition was inferred either from the soil survey data, soil placement mechanism, or elevation contours. Codification varied from country to country and between databases, making it important to find a detailed explanation of code meanings for proper and useful interpretation. Also to be considered was that soil surveys in the Caribbean are more commonly performed for agricultural use, rather than geotechnical evaluation, requiring additional interpretation in some cases, as well as the presence of unnecessary data. Resolution is varied with the data sources. However, liquefaction is a localized failure mechanism and as a result of varied soil and groundwater conditions occurrence may vary within the same soil deposit and seismic event for parcels of any size.

Seismic hazard analyses are expressed as either curves of probability (or return period) versus ground motion parameter for a specific site or by conversion of the curves to map contours describing ground motion parameter values for a given return period. The examples utilized in this study are the latter, providing peak ground acceleration (PGA) at a 475 year return period, or 10% probability of exceedance in 50 years (Bozzoni, et al., 2011; Wiggins-Grandison, et al., 2013). Values from these contours were interpreted and applied to each of the GIS land parcels and used to calculate probability of liquefaction under various magnitudes.

3.3 Data Sources

The compilation of data used in this study represents both publicly available data in the form of hazard maps, soil information, and aerial imagery, and information collected directly from officials, community leaders, and researchers in Jamaica and Trinidad through visits to the islands in question. Data collected during the visits included not only specific GIS, geologic, and seismic information, but also impressions of construction methodology and landforms that contributed to the selection of values for the GIS liquefaction susceptibility and hazard maps. The data and corresponding sources are shown in Table 3.1.

Table 3.1 –Sources utilized for GIS value development

Location	Data Type	Source
Jamaica	GIS	Digital Soils Map of the World (Food and Agriculture Organization of the United Nations, 2003)
	Soil Type	Digital Soils Map of the World (Food and Agriculture Organization of the United Nations, 2003)
	PSHA	University of the West Indies Mona Earthquake Unit
	Geology	Jamaica Water Resources Assessment (Miller, Waite, & Harlan, 2001)
		Jamaica - Geology Map (McFarlane, Lyew-Ayes, & Wright, 1977)
		Google Earth Aerial Imagery
Trinidad	GIS	University of the West Indies Department of Geomatics Engineering and Land Management (Soils25000 and Geology 10000 layers)
	Soil Type	Soil Capability Survey of Trinidad and Tobago (Brown C. , 1965)
	PSHA	Probabilistic seismic hazard assessment at the eastern Caribbean islands (Bozzoni, et al., 2011)
	Geology	Sustainable Cities: the Case of Greater Port of Spain (Beard & Claire, 2012)
		Flood Susceptibility Map Trinidad (2011)
		Trinidad Hazard and Response Map (Brown L. , 2010)
		Google Earth Aerial Imagery

3.3.1 Jamaica

Soil data for Jamaica was obtained from the Digital Soils Map of the World (DSMW) a program organized by the Food and Agricultural Organization of the United Nations with the goal of obtaining high-resolution soils data for academic and public use in planning and research (Food and Agriculture Organization of the United Nations, 2003). Designated for agriculture, soil chemical values are also included as well as the grain size distributions necessary for liquefaction evaluation. In Jamaica, the data is of relatively low resolution, particularly in comparison to that provided for Trinidad. These regions were classified based on their dominant soils, as provided by the DSMW generalized soils table, which provides average particle size distribution for each of the soil types. A description of the various soil types and assigned susceptibilities is included in Appendix A. While processed at a lower resolution, this dataset allows for greater coverage and more conservative selection of values by utilizing portions of each parcel with the highest susceptibility, rather than dividing the regions into many smaller parcels. This level of resolution would likely be more useful in a larger nation where only general liquefaction trends are necessary.

Seismic data was collected from seismic hazard maps provided for construction and as application documents for the International Building Code by the University of the West Indies Mona Earthquake Unit. This group has primary responsibility for the monitoring and analysis of the West Indies Seismic Network as well as for developing, updating, and publishing hazard maps for Jamaica and other parts of the Caribbean.

3.3.2 Trinidad

GIS data utilized in development of maps for Trinidad was obtained through the University of the West Indies Department of Geomatics Engineering and Land Management.

This directly sourced data was of a considerably higher resolution, including thousands of separate parcels with detailed descriptions of soil and land use.

Soils were identified in 1965 during a nation-wide soil survey that took place over several years (Brown C. , 1965). This system uses a two-digit numeric code to identify a given soil type and adds a third digit for small variations (either technical or geographical) for soils that fall into the same family. The extensive descriptions of these soils and descriptions of their structure and grain size distributions, as well as their locations on the island and their most common geologic formations were used to determine their level of susceptibility. Seismic values for Trinidad were adapted from the Bozzoni et al. (2011) PSHA for the eastern Caribbean as they were provided to the UWI Seismic Research Centre. The values determined incorporate numerous seismic zones with strong earthquake histories and consistent activity, as well as the faults on the island.

3.4 Summary

Definition of accurate parameters for evaluation of liquefaction susceptibility and hazard, particularly when using GIS, requires the use of numerous data sources for comparison. Compilation of these datasets enabled the extension of existing GIS soil and geologic layers to reflect susceptibility values, ground motion parameters, and the potential for liquefaction. Examples of the sources utilized for classification throughout the study are included in Table 1.

CHAPTER 4: SUSCEPTIBILITY BASED ON SOIL CHARACTERISTICS

4.1 Introduction

Youd and Perkins (1978) identified the need for a practical method for the mapping of qualitative liquefaction susceptibility in regions with limited records of geotechnical investigation. In order to facilitate this, a wide variety of earthquakes were studied to identify the susceptibility in areas of varying soil type, geography, and age. These values were presented to be assigned to individual soil parcels or geologic divisions to provide a qualitative estimate of the potential for an area to liquefy under strong ground motion, a magnitude greater than 5.0 (Youd & Perkins, 1978). Emphasis in this system of categorization is placed on alluvial and plains regions due to their generally higher susceptibility to liquefaction. Mountainous regions, which include the highlands of both Trinidad and Jamaica, have lower susceptibility due to their rocky soil and lesser groundwater presence in comparison to the large alluvial parcels, including alluvial fans, floodplains, and swamps. By comparison, the highland regions are of low susceptibility to liquefaction under the same ground shaking. The younger geologic age of lowlands areas, beaches also contributes to an increased susceptibility on Youd and Perkins scale, as shown in Table 4.1. Youd and Perkins also noted the comparison between uncompacted and compacted fill, applying “Very High” and “Low” susceptibility levels respectively.

Table 4.1 - Qualitative liquefaction susceptibility values, reproduced from Youd and Perkins (1978)

Type of deposit (1)	General distribution of cohesionless sediments in deposits (2)	Likelihood that Cohesionless Sediments, When Saturated, Would Be Susceptible to Liquefaction (by Age of Deposit)			
		<500 yr (3)	Holocene (4)	Pleistocene (5)	Pre-pleistocene (6)
		(*a*) Continental Deposits			
River channel	Locally variable	Very high	High	Low	Very low
Flood plain	Locally variable	High	Moderate	Low	Very low
Alluvial fan and plain	Widespread	Moderate	Low	Low	Very low
Marine terraces and plains	Widespread	—	Low	Very low	Very low
Delta and fan-delta	Widespread	High	Moderate	Low	Very low
Lacustrine and playa	Variable	High	Moderate	Low	Very low
Colluvium	Variable	High	Moderate	Low	Very low
Talus	Widespread	Low	Low	Very low	Very low
Dunes	Widespread	High	Moderate	Low	Very low
Loess	Variable	High	High	High	Unknown
Glacial till	Variable	Low	Low	Very low	Very low
Tuff	Rare	Low	Low	Very low	Very low
Tephra	Widespread	High	High	?	?
Residual soils	Rare	Low	Low	Very low	Very low
Sebka	Locally variable	High	Moderate	Low	Very low
		(*b*) Coastal Zone			
Delta	Widespread	Very high	High	Low	Very low
Esturine	Locally variable	High	Moderate	Low	Very low
Beach					
High wave energy	Widespread	Moderate	Low	Very low	Very low
Low wave energy	Widespread	High	Moderate	Low	Very low
Lagoonal	Locally variable	High	Moderate	Low	Very low
Fore shore	Locally variable	High	Moderate	Low	Very low
		(*c*) Artificial			
Uncompacted fill	Variable	Very high	—	—	—
Compacted fill	Variable	Low	—	—	—

After the initial classification based on soil composition and landforms containing the given soil parcel, the GIS was reviewed for discrepancies. Areas appearing to transition rapidly from a low to high risk were re-evaluated to ensure that an actual change in soil type or elevation was being indicated to ensure accuracy and continuity in the susceptibility map.

These qualitative classifications were then checked in comparison with a study of liquefaction susceptibility in the Laoag formation in the Phillipines (Beroya & Aydin, 2010). The proximity of the developed region to the ocean and seismic setting of the Caribbean islands allowed for reasonable comparison to the islands of the Phillipines, and, in the case of Trinidad, created GIS representations with considerable similarity to the Laoag and San Juan studies, both of which included soil data with similar resolution to the Trinidad database (Beroya & Aydin, 2010; Hengesh & Bachhuber, 2005; Macari & Hoyos, 2005).

4.1.1 Considerations

Soil type selection and susceptibility values were made using average or characteristic (dominant) values provided for each given soil parcel by the GIS dataset. Soils are, however, naturally variable and these values are not necessarily representative of specific areas within a given deposit, nor can they represent the actual stratification of the soil. As a result, there is a natural uncertainty with regard to susceptibility.

The mountainous inland sections of the islands are largely volcanic material and have inherently low liquefaction susceptibility, but the lower alluvial areas are liquefiable sediments much younger in geologic age. Youd and Perkins (1978) values for younger soils were used for evaluating these regions. Holocene and younger age levels were selected for soil assessment on both islands as most susceptible regions also have high variability with time due to the effects of aging on soils.

Youd and Perkins (1978) mentions the requirement that groundwater either saturates the liquefiable layer or is near enough to the layer such that earthquake induced groundwater rise could create saturated conditions in the liquefiable strata. Susceptible layers on the islands tend to lie in either near-coast soil deposits or in the floodplains of rivers. As a result of these two conditions, the assumption was made that there is a high potential for a groundwater table near the surface in liquefiable areas, even where groundwater does not generally exist. Considering especially floodplains and the hurricane and variable rainfall of the Caribbean, a near-surface groundwater table would a conservative value for both methodologies used in this study.

Developed areas with high volumes of reclaimed material are subject to high variability of fill processes and control of fill material, as well as unknown history and aging. This resulted in the choice to use a “Very High” susceptibility value for areas with large deposits of fill material (Youd & Perkins, 1978). Fill sites must be tested individually using in situ test methods to accurately grade response to earthquake loadings, and still have the potential to vary significantly within the site.

4.2 Jamaica

The third largest island of the Caribbean, Jamaica has a varied geography that induces highly variable susceptibility. Areas of soil were considered based on the general properties given by the DSMW, and values were assigned to reflect these properties and the placement of the deposits.

4.2.1 Geography

Jamaica is primarily mountainous, although significant alluvial deposits from watershed outlets lead to the shoreline. The mountainous inland is steeply sloped and incorporates metamorphic and igneous materials (McFarlane, et al., 1977). These areas lie mostly above the water table, and although at risk for landslides (which have been recorded and assessed on the island) there is a lesser liquefaction susceptibility with the exception of areas adjacent to waterways. Much of the major development on the island is on the lowlands sediments, including reclaimed land and construction on the alluvial soils themselves. Each of these placements increases the hazard of liquefaction. Kingston, the capital of the country, is built on an alluvial area, and the primary airport in the capital is built on reclaimed land on the peninsula ("spit") of land creating the Kingston Harbor, directly adjacent to Port Royal and noted by locals to wash out with wave action regularly.

4.2.2 Soil Types

The rapid variation of geologic formations from lowlands to mountains creates a situation of varied soil types for Jamaica in a very short range of distances. A summary of the grain size distributions for Jamaica's soils is shown in Table 4.2.

Table 4.2 - Jamaica soil descriptions and classifications (from DSMW)

Soil unit symbol	sand % topsoil	sand % subsoil	silt % topsoil	silt% subsoil	clay % topsoil	clay % subsoil	Youd & Perkins
AO	53.6	43.4	15.8	16	30.6	40.6	Moderate
BC	40.1	41.8	21.5	22.7	38.4	35.5	High
E	48.5	45	30.8	32	20.7	23	Low
I	58.9	56	16.2	17	24.9	27	Moderate
JE	70.8	67	12.8	14.1	16.5	18.9	Very High
LC	64.3	59	12.2	11.2	23.5	29.8	High
ND	38.9	31.9	17.6	13.8	43.6	54.4	Low

The mountainous regions consist mainly of rocky soils, and a primary industry of the foothills being bauxite mining, even very near to the coast. Due to their steep slopes and rocky compositions, some of which is intact rock, they are less impacted by liquefaction than by other types of ground failure. Elevation shifts rapidly, removing a large portion of the island from elevations where groundwater is regularly present to contribute to the liquefaction susceptibility. Coastal areas, due to both alluvial fan and coastal sediments are primarily loosely packed sandy material with a mix of clay and silt. This composition also applies to the northernmost portion of the island, which includes the Montego Bay area, known for the prevalence of resorts and tourism in Jamaica. Although Montego Bay is also primarily sand and alluvial material, similar to Kingston, the soil takes the form of a beach deposit rather than an alluvial fan. Figure 4.1 shows a soils map for Jamaica. The soil names provided in the legend are agricultural classifications supplied by the DSMW.

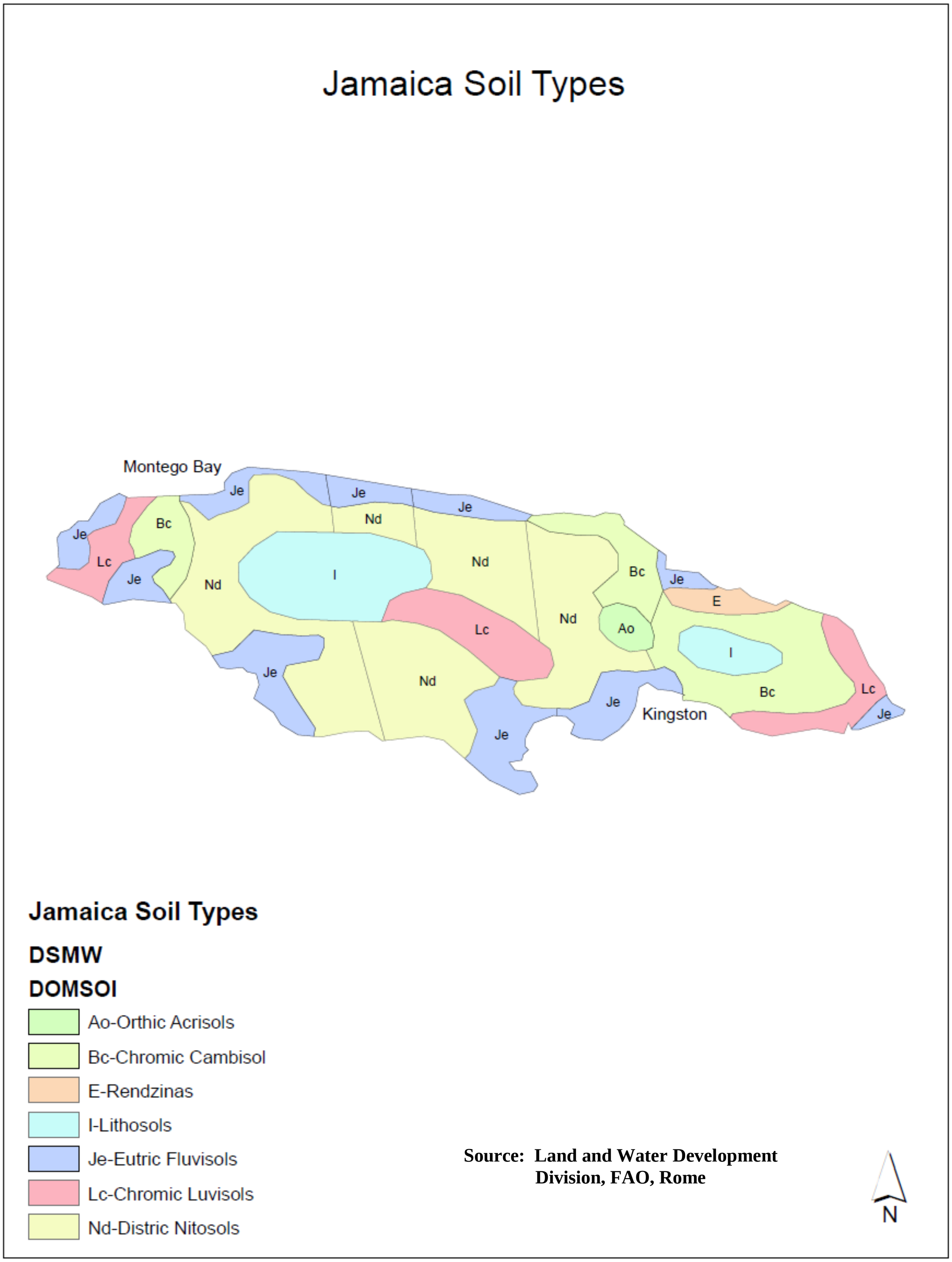

Figure 4.1 - Map of Jamaica showing variation of soil types

In effect, the island of Jamaica is a series of mountains intermittently broken by low-lying alluvial deposits. In many cases around the island, the mountains proceed directly into the sea with little or no beach area, eliminating much of the at-risk area (compared to other islands of the Caribbean) due to its lack of an extensive floodplain. These alluvial areas, because they are low lying and in proximity to the ocean, have relatively shallow water tables. The Water Resources Authority indicates that wells are common in the non-mountainous regions of the island, but water tables are only maintained in the mountains during moderate to high rainfall levels (Miller, et al., 2001).

4.2.3 Assigned Susceptibility Levels

Highest level of susceptibility in Jamaican soil was, as expected, found in the coastal areas of the island. The northern coast, eastern and western points, and southern coasts were assigned a “Very High” susceptibility due to their sandy composition and low elevation which creates a closer proximity to the groundwater table. This value was decided to be particularly appropriate for the region of Kingston. Primary reason for this choice was the city’s history of liquefaction and multiple hazard studies placing the area under a significant hazard, as well as its extensive use of reclaimed land, particularly in critical infrastructure construction (Hornbach, 2011). Liquefaction susceptibility of Jamaica is shown in Figure 4.2.

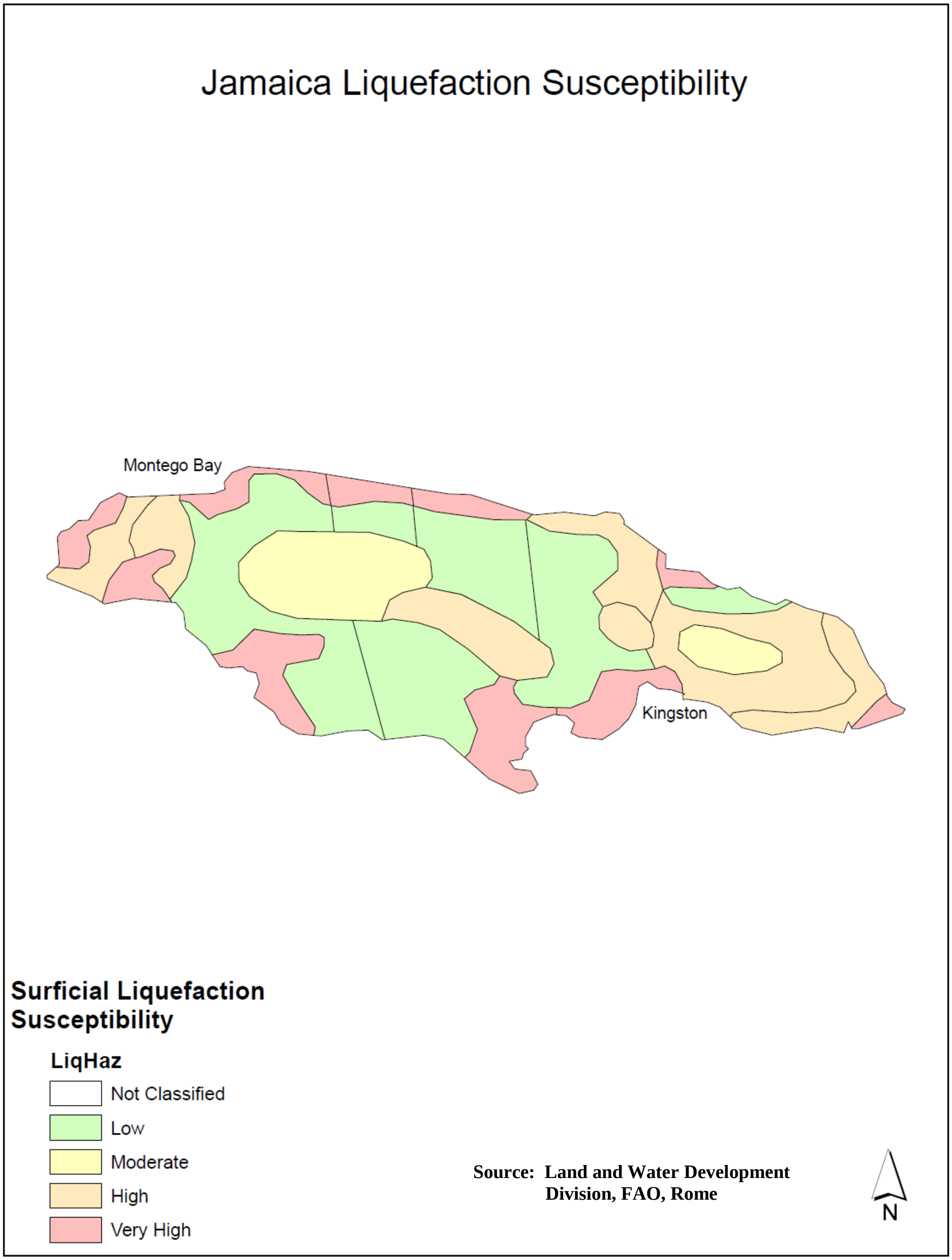

Figure 4.2 - Liquefaction susceptibility map of Jamaica based on Youd & Perkins (1978)

As the soil parcels became farther from the coast, the liquefaction susceptibility rapidly decreased as a result of the mountain geography. The majority of Jamaica's geography is not at a high level of susceptibility for liquefaction, but, conversely, the most densely populated areas lie along the coast where susceptibility to liquefaction is highest.

4.3 Trinidad

The variation of Trinidadian soils is more distributed than the stark contrasts existing in Jamaica. Several parcels of alluvial material create large areas of increased susceptibility which varied from coastal areas to inland waterway deposits.

4.3.1 Geography

Trinidad is divided into three main geologic areas. The Northern Range is a mountainous region with steep slopes and a considerable igneous faction, and is actually an extension of the South American Andean Mountains (The Cropper Foundation, 2005). This geologic region dominates the northern coast, which consists mostly of rocky beaches and cliffs. Soils are generally located above the water table in the northern region, which significantly reduces liquefaction hazard, although there remains a potential for suspended water tables due to low permeability soils and increases in water table elevation due to heavy rainfall. This area is also largely volcanic soil.

Just south of the Northern Range is an extensive alluvial plain, which includes the city of Port of Spain and the swamp lying directly to its south, although the city itself is built largely on reclaimed land, primarily the government district. The remainder forms two large watersheds, with one flowing to each the east and west coasts. The region furthest to the south is an alluvial and coastal plain. The latter two areas contain soils with the highest susceptibility to liquefaction in Trinidad.

4.3.2 Soil Types

Soil types in Trinidad vary widely across its three geologic regions. The Northern Range has largely rocky soils consisting of shales and sandstones. While these soils may have a high sand content, their position places them above the water table, and drainage is free, reducing the potential for a high water table and thus liquefaction although, like Jamaica, there is still a potential for alternative ground failure mechanisms. Some alluvial material exists in runoff channels leading down the mountainous terrain, providing small areas where liquefaction has the potential to occur. While susceptibility may be higher, this area is at a relatively low risk due to a lack of major development. The exception is the distribution of alluvial and marine (beach) deposits along Trinidad's northern coastline, which are largely liquefiable. The majority of the coast consists of rocky beaches, but several areas of runoff form delta and alluvial fan deposits. The combination of these areas with tidal sediment creates highly liquefiable soil. A soils map is shown in Figure 4.3. Most parcels at the provided scale are too small to accept labeling, and some colors are repeated. The 122 distinct soil types and their assigned susceptibility levels are shown in Appendix A.

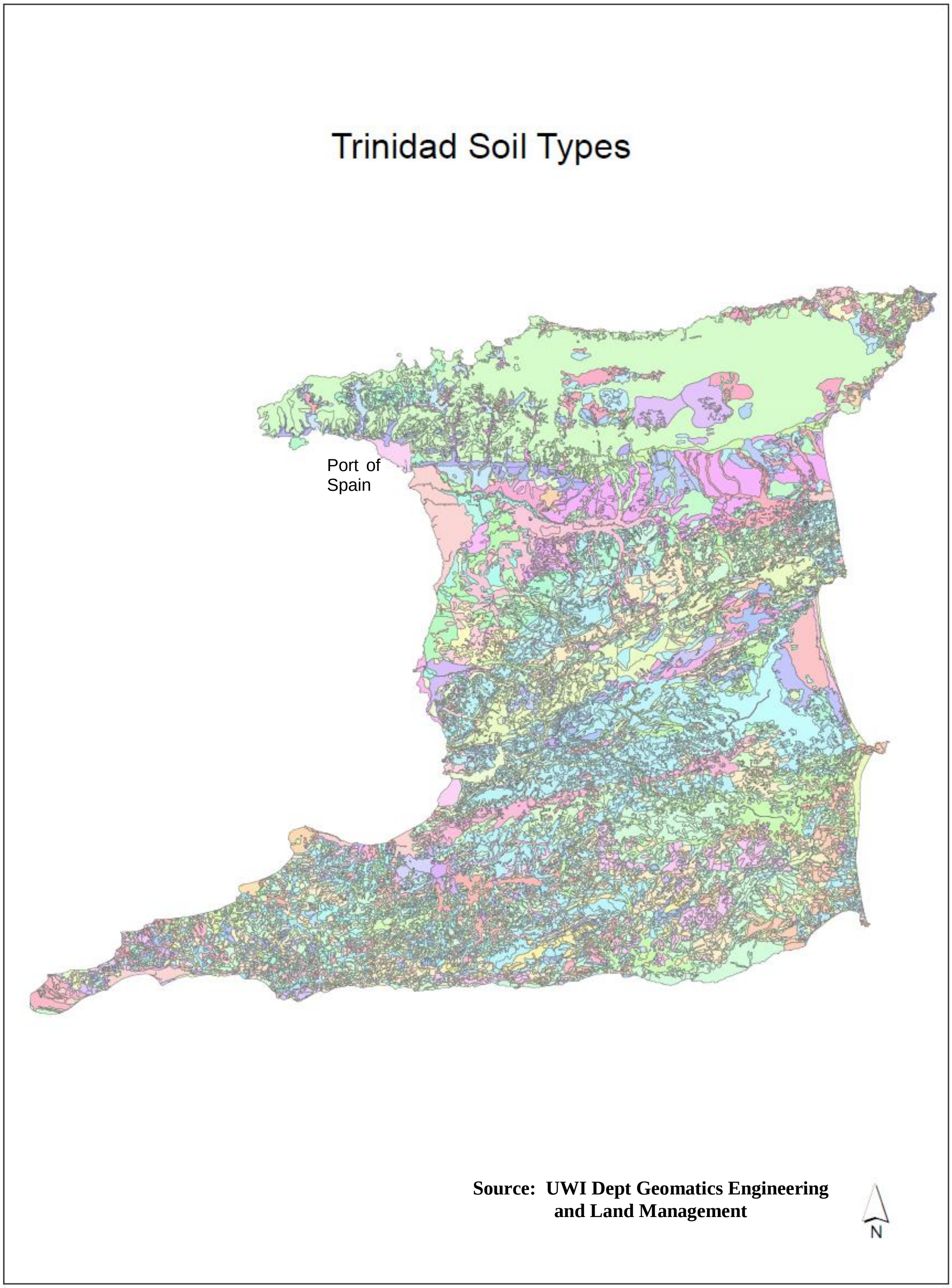

Figure 4.3 - Map showing variation of soils in Trinidad (values not labeled due to scale)

In the alluvial plain is a variety of sands and clays and combinations of permeable and non-permeable soils. Classifications of these soils varied based on the description provided for the soil survey. Several described as clays or silts contained considerable sand content or descriptions indicating potential for variance within the parcel, resulting in more severe liquefaction susceptibility. A large portion of Trinidad is an alluvial fan and deltaic swamp, on which there is a large amount of residential and commercial construction. Beyond the swamp, which is primarily clay, the alluvial deposits in the area are described as varying between sands, clays, and peats, indicating a heavily varied stratigraphy. These soils, due to their nature of formation, were assumed to be very young, particularly in comparison to the Northern Range.

Examining contours of the region reveals that throughout the alluvial plains region, and in the south of the island, the coastline is preceded by an expansive lowlands area. This increases the likelihood that the water table would be very near to the surface, enhancing the effects of ground motion and inducing liquefaction at a much lower level of acceleration. In addition, numerous coastal areas are industrialized with refineries or docks, requiring use of fill material. The composition of this fill material cannot be fully known, but was assumed to primarily be sand for ease of placement and compaction. In the absence of some means of stabilization or significant compaction, these sites will be subject to higher susceptibility.

4.3.3 Assigned Susceptibility Levels

Trinidad's highest susceptibility levels are found in the deltas and coastlines extending from its alluvial and coastal plains as shown in Figure 4.4.

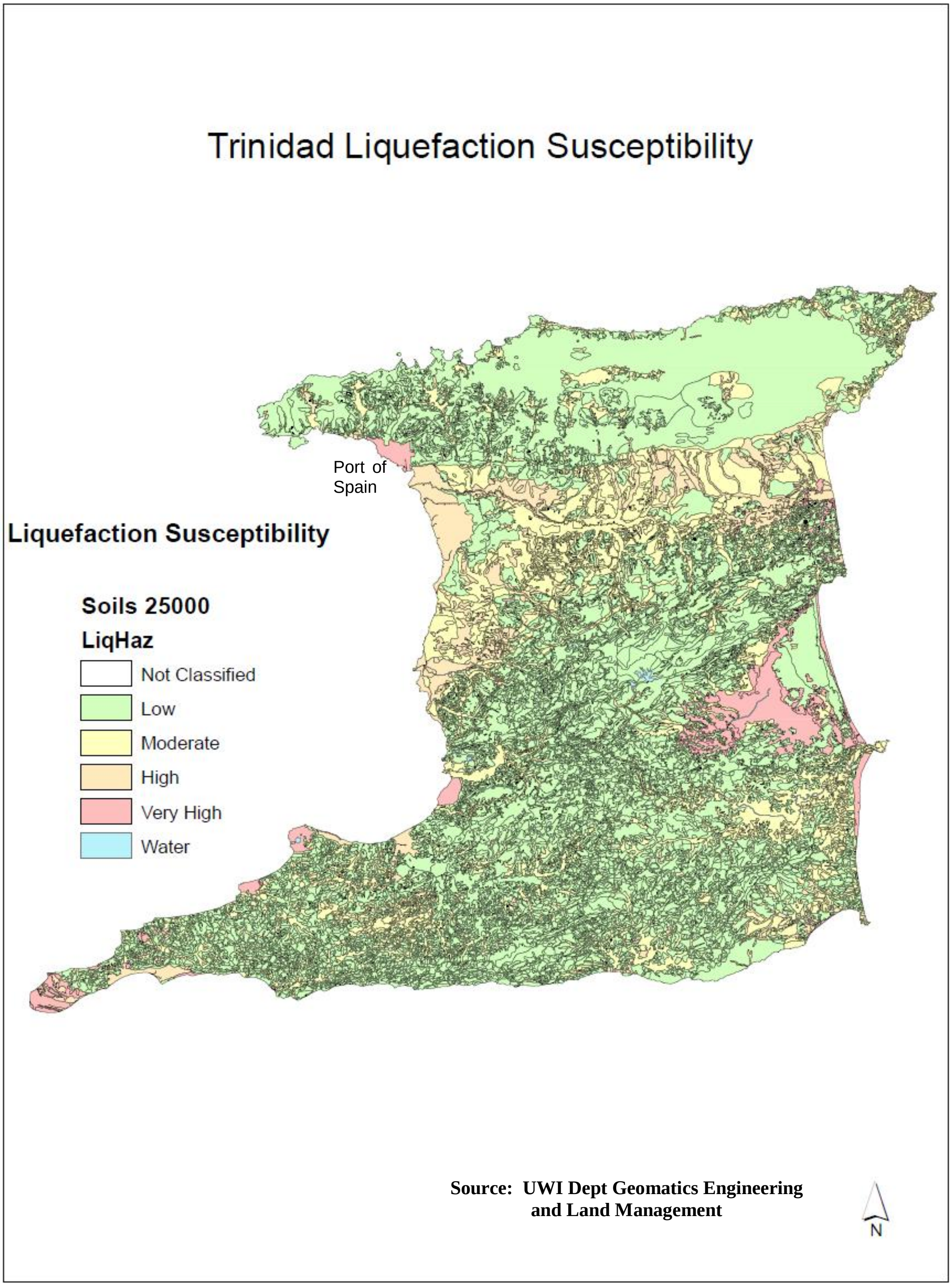

Figure 4.4 - Map showing liquefaction susceptibility of Trinidad based on Youd and Perkins (1978)

Numerous rivers and other waterways create numerous floodplains on the island, including the greater Port of Spain area. (Opadeyi & Thongs, 2011; Beard & Claire, 2012) This water condition and the large swamp and delta in the central expanse of Trinidad create a large region of susceptible soils. The less susceptible soil parcels in the same region is due to higher clay content in the soil. Also vulnerable are the many small bays and alluvial areas surrounding the island. These areas are formed largely of sand and silty sand along the coast, a sediment type well known to be highly susceptible to liquefaction.

The southern peninsula of the island is also a deposit more susceptible to liquefaction including a large area of beach deposits as well as freshwater flow paths. Several areas along the eastern coast were also given a "High" level of susceptibility due to construction on fill or beach and alluvial deposition.

4.4 Summary

Both of the countries studied show a very high level of susceptibility at and near the coasts, as expected. Susceptibility tends to decrease as the area of consideration is moved further inward and higher in elevation, with the exception of areas adjacent to waterways. The prevalence of coastline lacking significant beach deposits did create a surprising reduction in susceptibility near the coast on both islands, but given their rocky composition, this falls within the understanding of the Youd and Perkins assessment methodology. Also surprising is the degree to which urban development in both nations tends to be gathered in areas of higher susceptibility, even progressing across the alluvial plain in Trinidad as shown in Figure 4.5. The number of people residing in liquefiable zones increases their potential impact during a major earthquake.

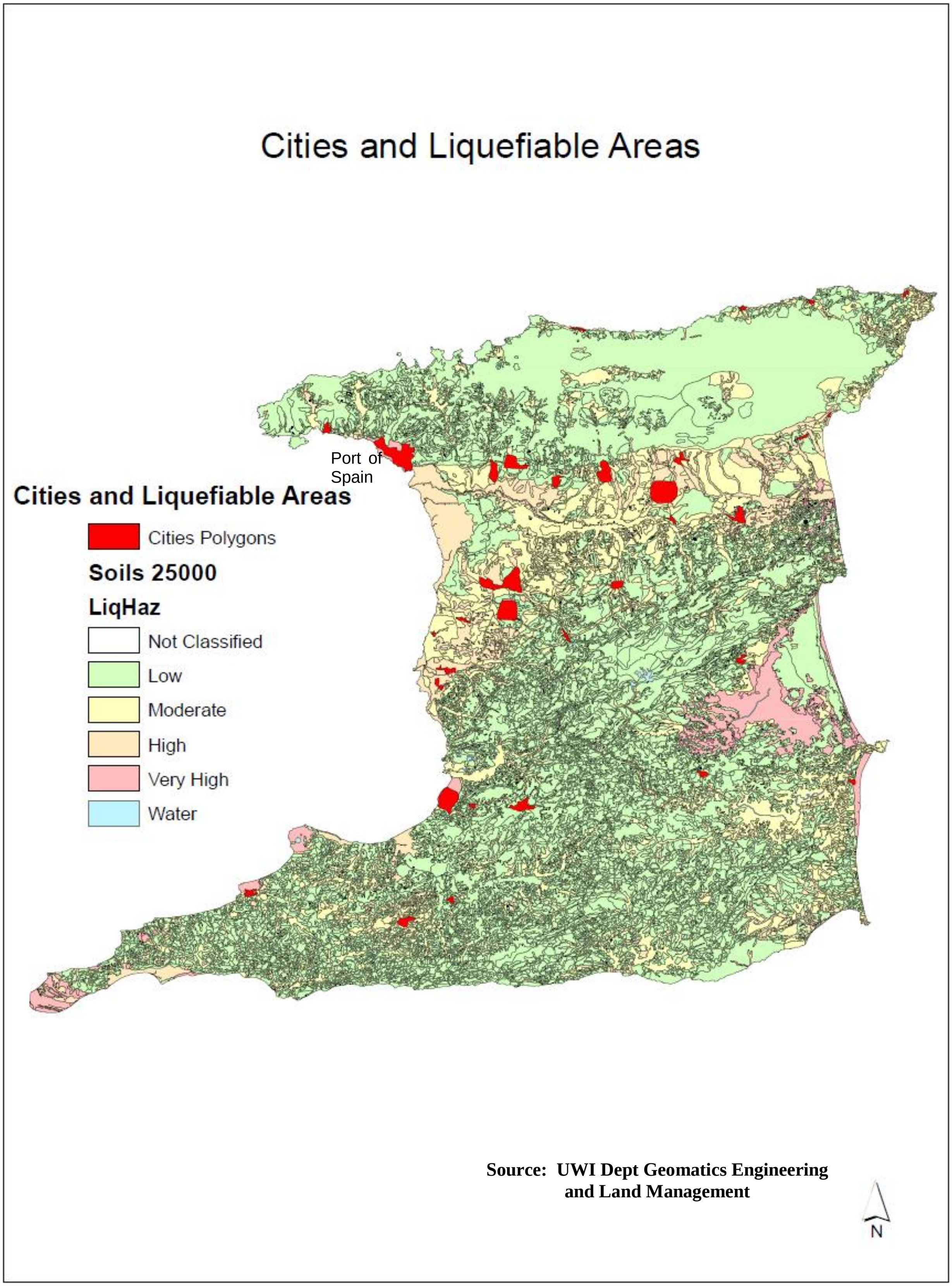

Figure 4.5 - Liquefaction Susceptibility of Trinidad showing city locations (bright red)

CHAPTER 5: GEOLOGIC AND PROBABILISTIC MAPPING

5.1 Introduction

The theory of probabilistic liquefaction hazard analysis applied in this study was developed by Holzer, et al. (2011) in order to provide a means to evaluate liquefaction hazard without extensive in-situ or laboratory testing. Other means of liquefaction analysis require a thorough understanding of the subsurface before a probability value can be assigned, including such values a groundwater availability, area of the deposit, and thickness of the liquefiable fraction, among others (Youd & Perkins, 1987; Toprak & Holzer, 2003). Holzer et al. (2011) uses a series of earthquake events in the United States to develop probability values for liquefaction in a variety of surficial deposits, rather than basing the values on individual soil characteristics. Susceptibility values assigned in Chapter 4 identify only the qualitative tendency of a given soil deposit to liquefy under general seismic conditions. The hazard values assigned in Chapter 5 show the probability of liquefaction for deposits given an earthquake magnitude and the assigned acceleration value for the region.

5.2 Methodology

Each of the two islands was approached with the same process. Most important during the process was that all possible regions evaluated by Holzer et al. (2011) were designated accurately to provide the most information possible for liquefaction hazard evaluation. Both of the islands have rapidly changing landforms and efforts were made to reflect the provided GIS parcels as accurately as possible in their classification. Similar to Chapter 4, generalizations are made with the objective of a conservative analysis. That is to say, if a parcel was equally distributed between two geologic units, the higher hazard curve was chosen. In the same way, as contours were used, the higher contour value was utilized to achieve a more conservative hazard calculation.

1. Islands assigned geologic unit based on descriptions provided by Holzer et al. (2011), soil characteristics, aerial imagery (Google Earth), and supplementary data.
2. Acceleration value (PGA or PHA as surrogate) chosen using PSHA map for the region.
3. Corresponding probability value determined from fitted curve for the geologic unit.
4. Process repeated for all parcels and magnitudes

Ideally, with disaggregated magnitude data and hazard curves available, the process adopted by Kramer and Mayfield (2007) is a more accurate and appropriate determination of probabilistic liquefaction hazard. However, these values were not available, and the adopted procedure therefore serves to represent the variation of liquefaction hazard with magnitude.

5.2.1 Geologic Assignment

Soil type, geologic information, aerial photography, and any other available information (flood hazard maps, geologic maps) were applied to determine the type of geologic deposit. The geologic or soils layers of the GIS data were evaluated based on visually characteristic landforms, such as alluvial fans and riverine beds, specific descriptors (i.e. "Swamp"), and contours from either the GIS or external maps. Contour lines became particularly useful during these determinations to determine extents of liquefiable area. To check for accuracy, the choices were compared with other studies applying the same types of geology (Beroya & Aydin, 2010; Holzer, et al., 2005; Youd & Perkins, 1978). It is important to note that only a specific subset of geologies is evaluated for liquefaction probability, which results in a large portion of parcels that do not receive assigned values under this analytical process due to a comparably lower level of associated hazard.

Unlike the susceptibility classification, the geologic assignment for this process was not based on soil composition. Areas falling under the same surficial geologic unit have the potential to contain numerous types of soil composition and susceptibility classes. For example, an alluvial fan region could contain both highly liquefiable sand as well as clay at a very low susceptibility. Like the Youd and Perkins process, the overall GIS was checked for discrepancies between and within surficial geologies and to ensure accuracy and continuity throughout the maps.

5.2.2 Acceleration Determination

Peak acceleration values for each parcel were selected from the respective PSHA for each of the countries. This selection considered the most prevalent peak acceleration value for each of the geologic parcels. In some cases, portions of the parcels extended well beyond a single peak acceleration value, in which case the peak acceleration with the greater impact was chosen. In cases of an even amount, the more severe acceleration value was chosen to account for the worst case. The extreme case of Jamaica's largest soil parcels required division of the parcel into multiple sub-sections to accommodate the distribution of acceleration values. This was necessary for three of the soil parcels.

5.2.3 Probability of Liquefaction

Holzer et al. (2011) provides liquefaction probability curves based on a series of CPT liquefaction potential indices for the different geologies. As a result, they have the potential to better estimate the possibility of localized liquefaction than soil classifications that assume a single value for an entire soil parcel by incorporating distributed soil types. These probability curves were designed to be extended to other regions with similar surficial geology. PSHA values for PGA could be used in combination with the Youd et al. (2001) magnitude scaling factor (MSF) to account for duration of earthquakes at various magnitudes. PHA for the same return period was used as a surrogate for PGA in the case of Jamaica.

$$MSF = \frac{10^{2.24}}{M^{2.56}}$$

Collected Liquefaction Potential Indecies (LPI) across the numerous sites and seismic events were evaluated to establish probability curves for liquefaction at the varying geologies (Toprak & Holzer, 2003). This survey was fitted with a three parameter curve, where a, b, and c vary with each of the different types of surficial deposits (Holzer, et al., 2011).

$$p = \frac{a}{1 + \left(\frac{PGA/_{MSF}}{b}\right)^{c}}$$

This value is a probability of liquefaction occurring in the given soil deposit for an earthquake of given magnitude and acceleration occurring at that site. Curves are generally presented as probability vs. PGA/MSF. Figure 5.1 shows the variation of probability across different surficial geologies for a given magnitude. Probability values for all acceleration values, magnitudes, and geologic units are shown in Appendix B, while curves for each of the five magnitudes used are shown in Appendix C.

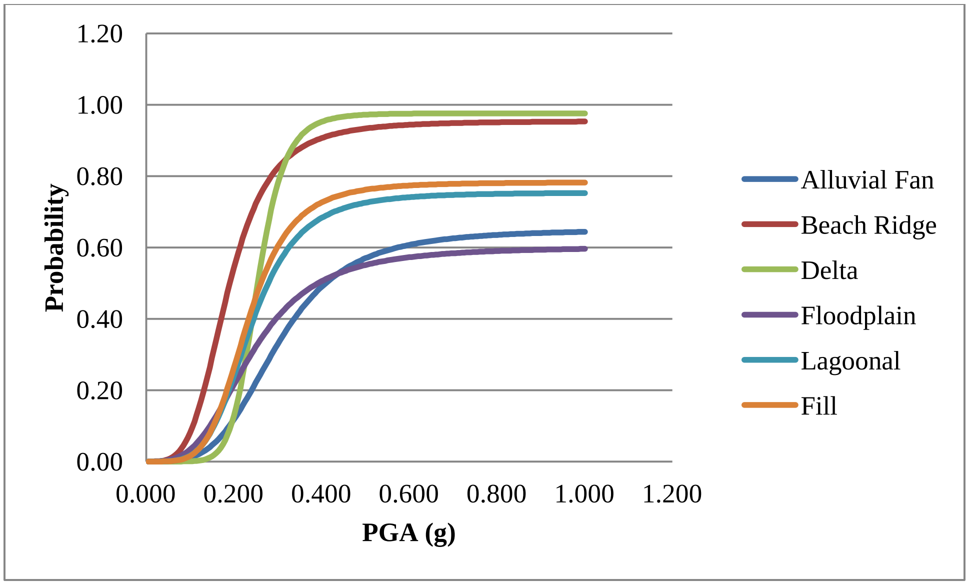

Figure 5.1 - Liquefaction hazard with M=7.5 (MSF approximately equal to 1)

The choices with regard to hazard curves were based on efforts to select the most similar type of deposits. Younger deposits in the areas of alluvial fan and beach ridge geologic units were chosen to coincide with the susceptibility analysis. Topset delta values were chosen for a younger age delta, providing more conservative values, and floodplain basin deposits were used, as point bar deposits in high flow rivers (the Mississippi River) would not accurately reflect flow on the islands. For lagoonal and fill units, there was only a single curve available. Probability curves for each deposit and magnitude are presented in Appendix B.

The use of a MSF requires the peak acceleration values to be calculated with consideration to a range of magnitudes. Magnitudes and MSF values used for this study are shown in Table 5.1. They are well within the range of recorded activity for each of the two islands.

Table 5.1 - Magnitude and magnitude scaling factors used

Magnitude	MSF
7.5	1.000
7.0	1.193
6.5	1.442
6.0	1.770
5.5	2.211

Holzer et al. provides curves for groundwater tables at depths of 5 meters and 1.5 meters. The proximity of the majority of the liquefiable soil deposits to sea boundaries or their alluvial nature, probabilistic curves for a water table of depth 1.5 meters were used for calculation. This accounts both for standard conditions as well as conditions of heavy rain. Rainfall in the Caribbean is highly variable, particularly considering the hurricane threat to the area. The common flooding conditions indicate a water table capable of reaching the ground surface on both islands (Opadeyi & Thongs, 2011; Lyew-Ayee Jr., et al., 2009). Periods of lower rainfall or even drought would reduce risk in inland areas, due to the lower water presences, but as population is concentrated mainly along the coast, there would be lesser effects to overall risk. The higher water table was therefore once again deemed a reasonable and conservative assumption for purposes of the analysis.

5.3 Jamaica

Jamaica's mountainous geography reduced the area of classified zones, as the mountains are regarded as non-liquefiable units. The surficial geology classification is shown in Figure 5.2.

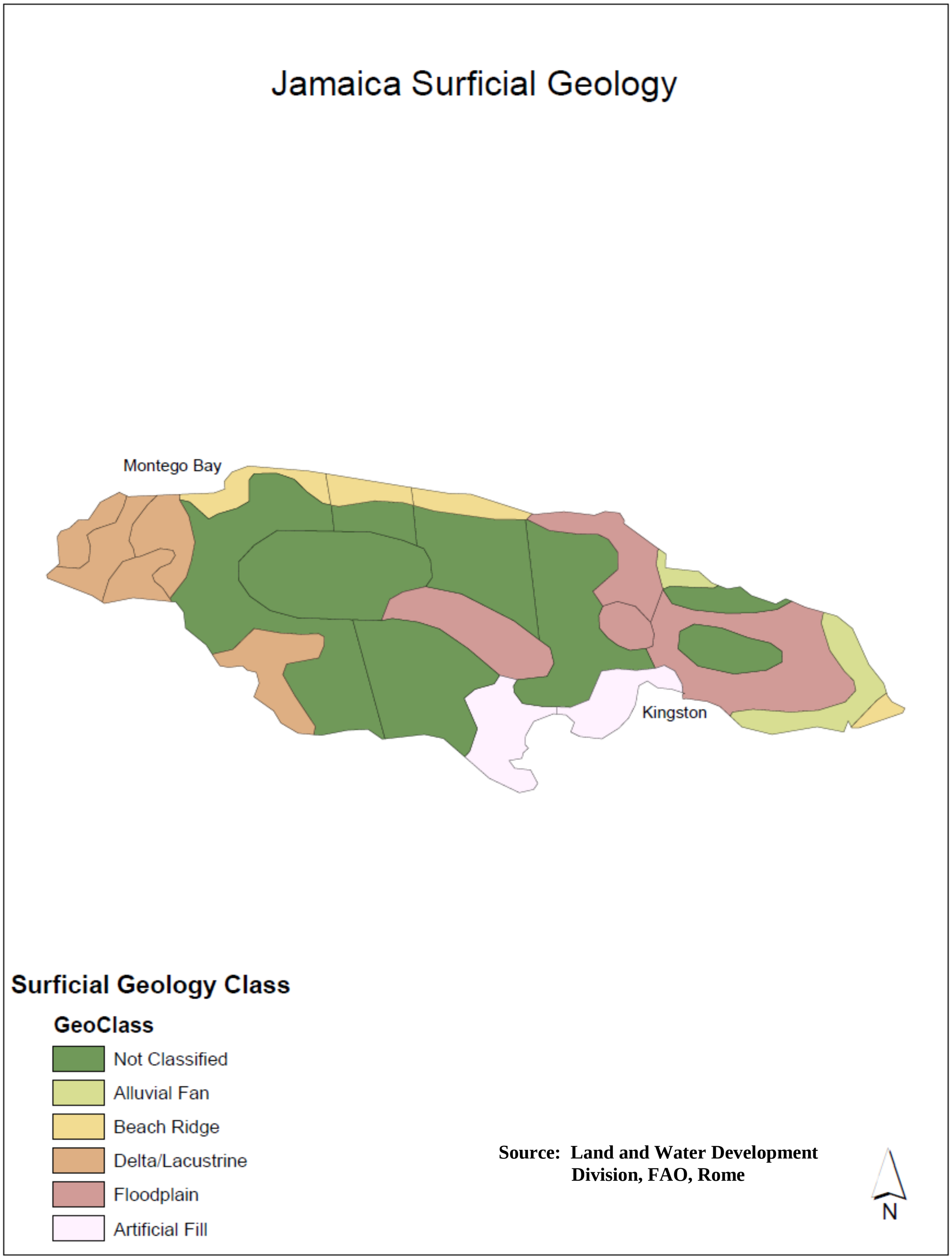

Figure 5.2 - Jamaica surficial geology classifications

Beach ridge and delta deposits are located at either end and along the northern coast, in the area of Montego Bay. The south contains deltaic areas, although the City of Kingston was classified as a fill unit due to local knowledge of its historical development. Several floodplains extended into the island based on flood hazard maps (Wiggins-Grandison, et al., 2013). Note in particular western Jamaica, where in comparison to the Youd and Perkins values, which included two levels of susceptibility and two soil types, the region is now regarded with a single (deltaic) surficial geology classification. These regions, subdivided to correspond with PGA as mentioned previously, were assigned acceleration values as shown in Figure 5.3.

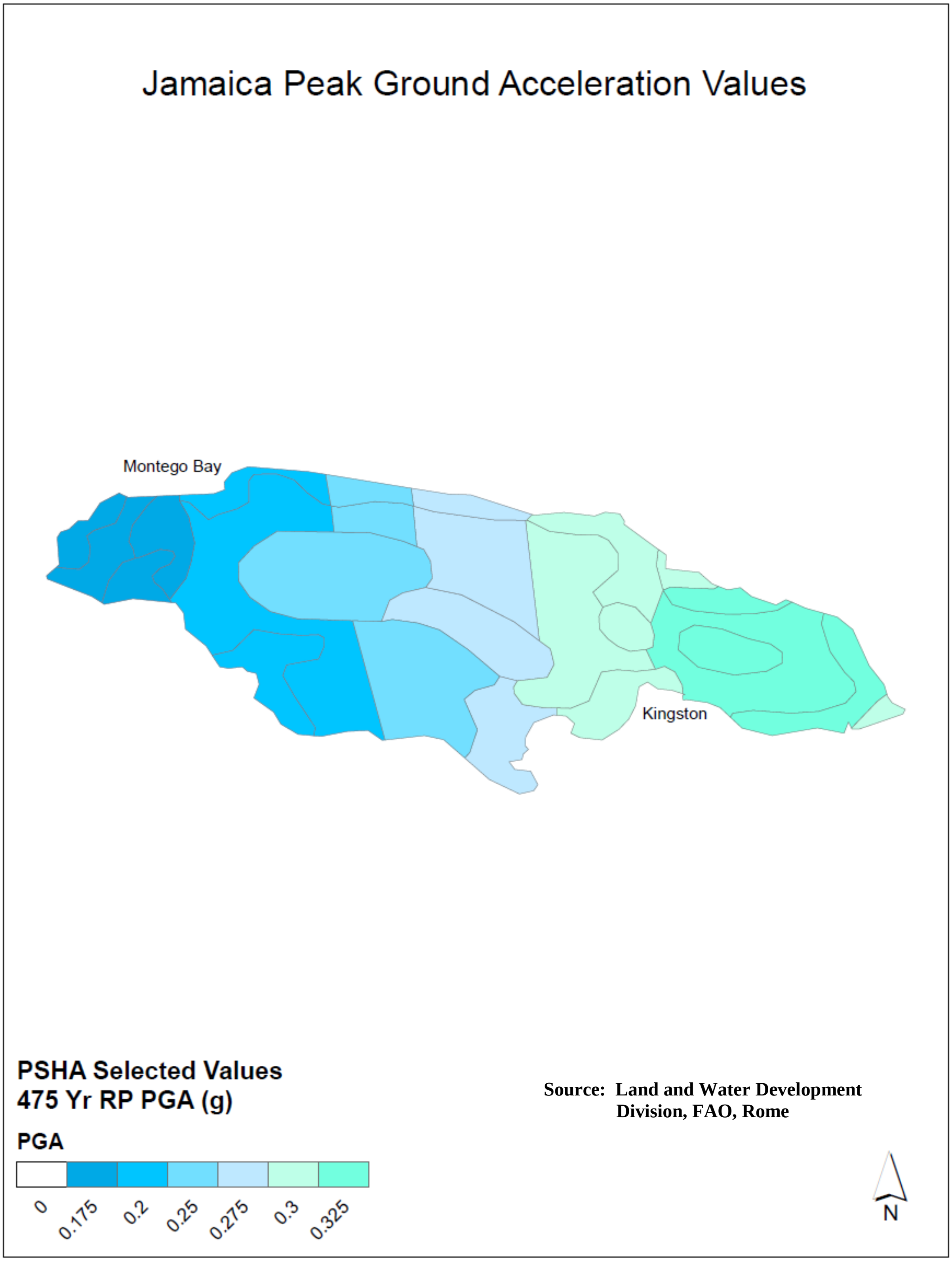

Figure 5.3 – Peak ground acceleration for Jamaica, reproduced from Shepherd et al. (1997)

Peak ground acceleration as provided by the PSHA map for the 475 year return period had a maximum value of 0.325 g centered in the Blue Mountain region of the island, just northeast of Kingston and in the area of the Enriquillo Plaintain fault. (Shedlock, 1999) From there, acceleration values decrease to 0.175 g at the western end of the island. The area of highest acceleration directly neighbors greater Kingston. Combination of the geological and PGA maps with the probability equation yielded the liquefaction hazard maps, shown from highest to lowest magnitude in Figures 5.4 through 5.8.

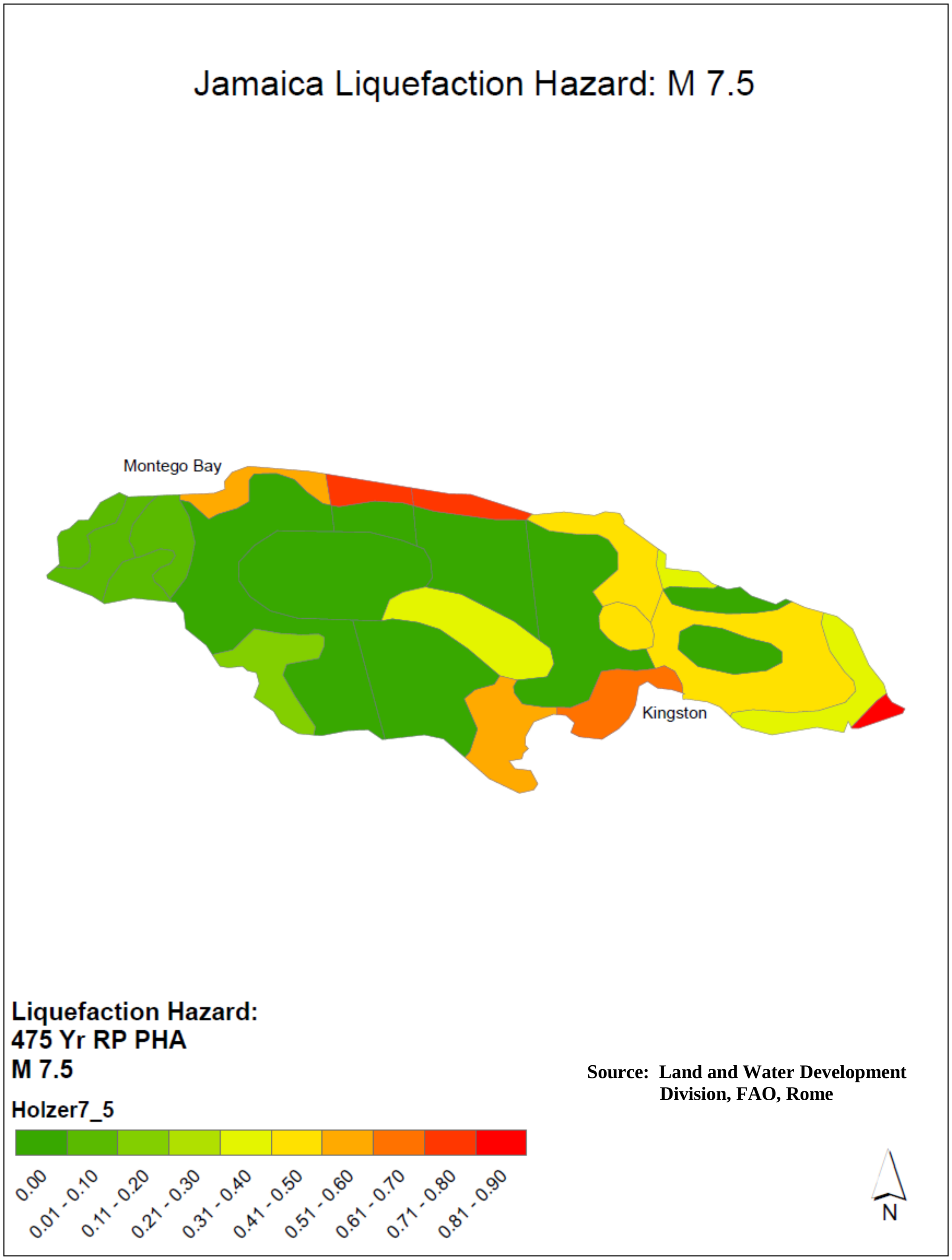

Figure 5.4 – Jamaica liquefaction hazard, M=7.5

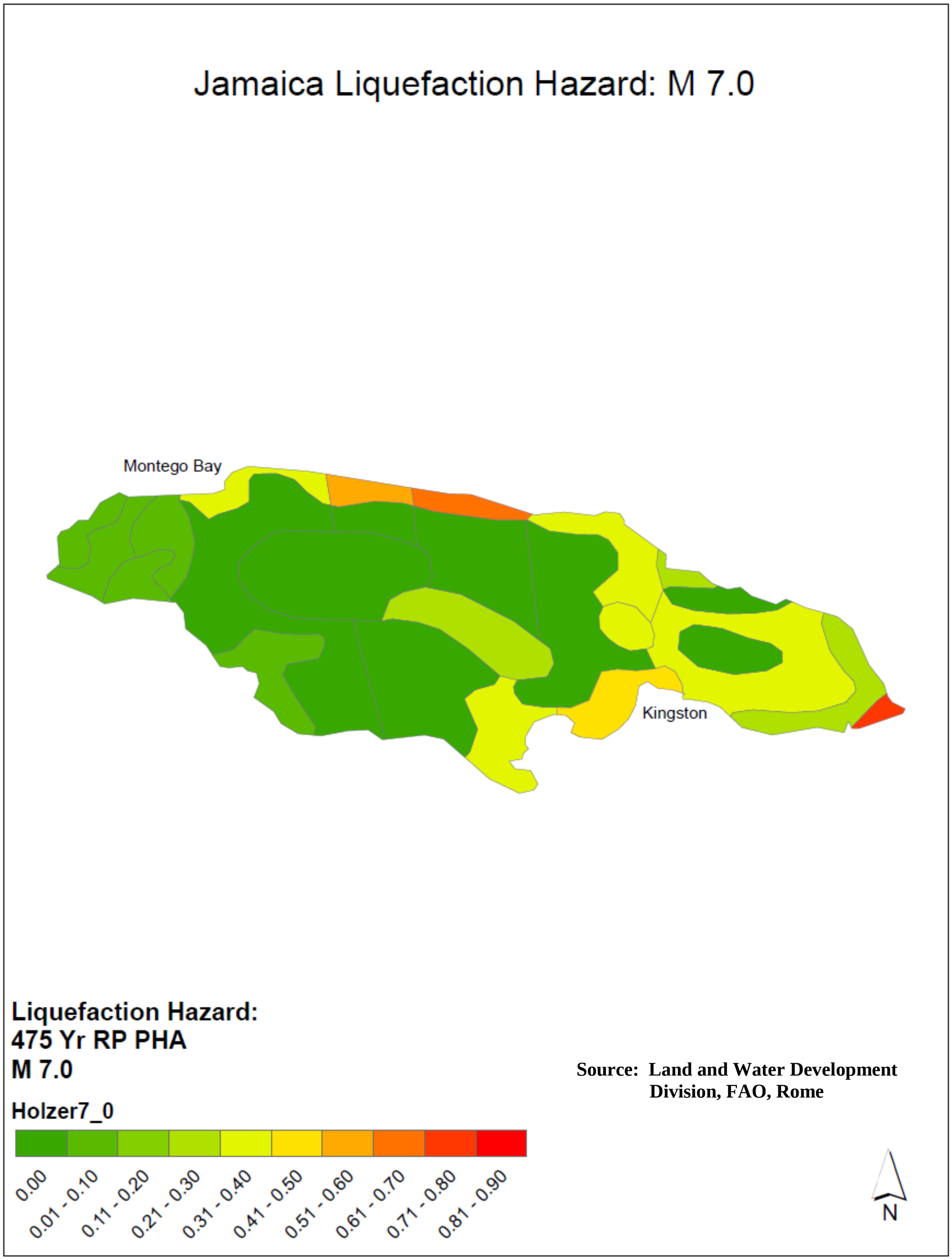

Figure 5.5 - Jamaica liquefaction hazard, M=7.0

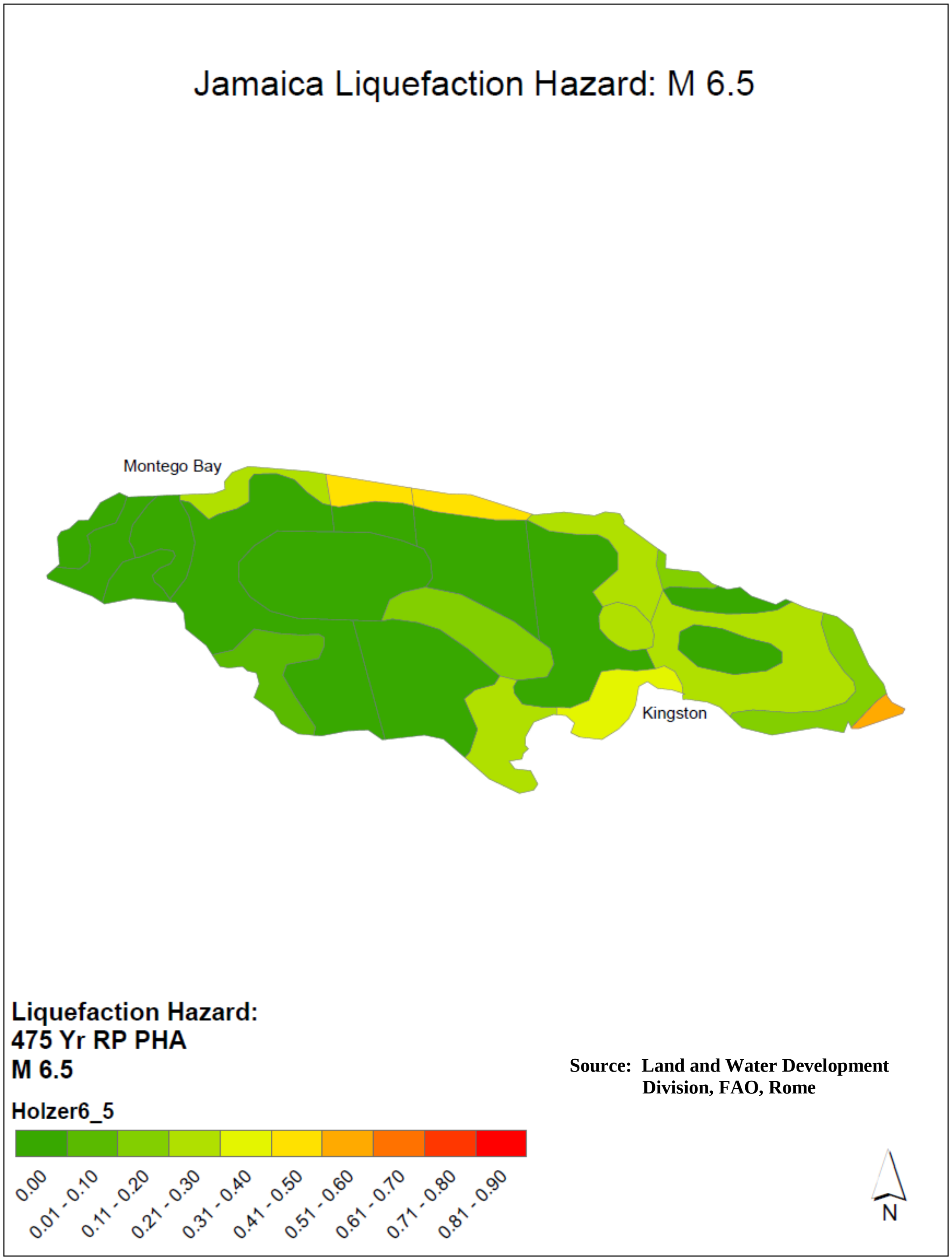

Figure 5.6 - Jamaica liquefaction hazard, M=6.5

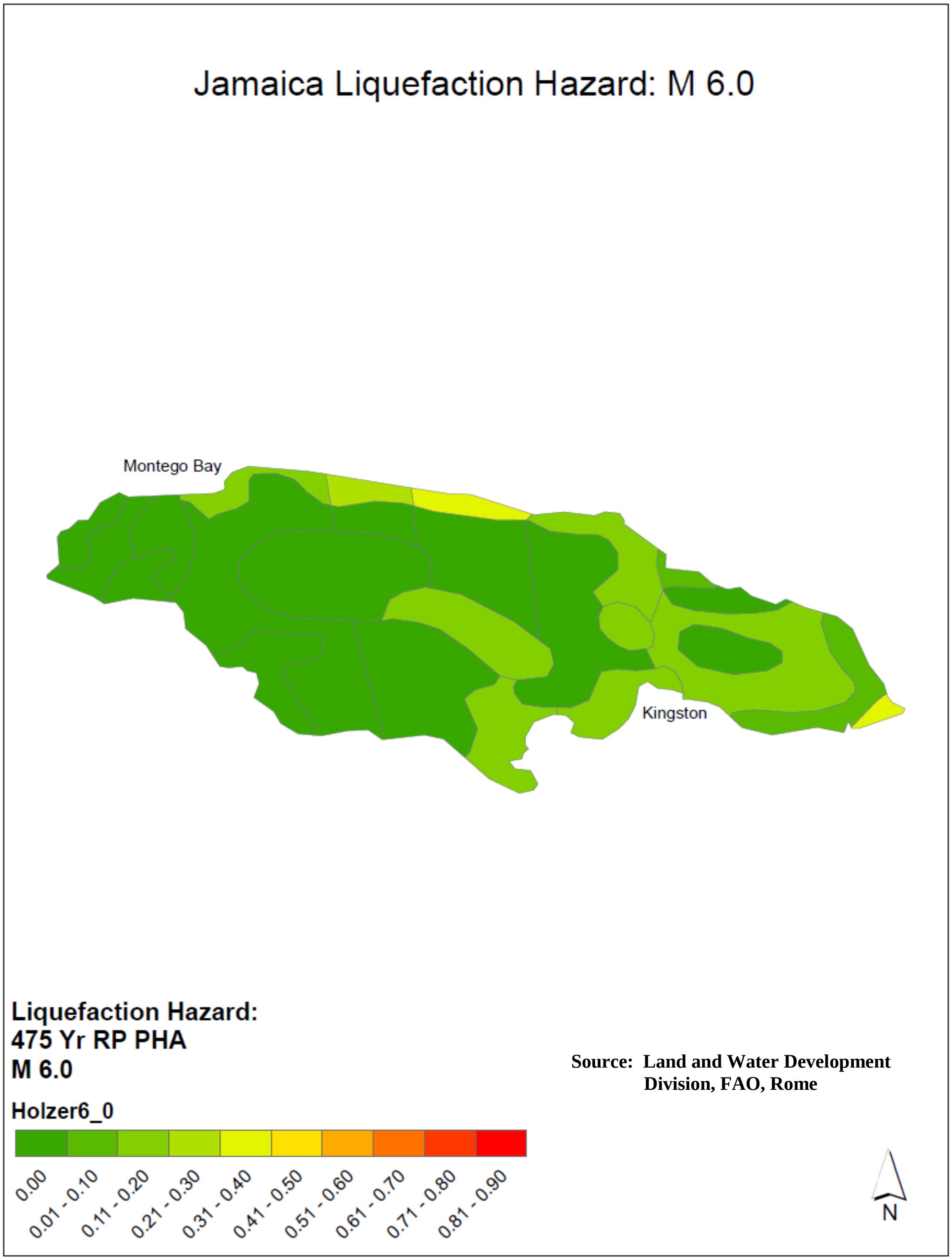

Figure 5.7 - Jamaica liquefaction hazard, M=6.0

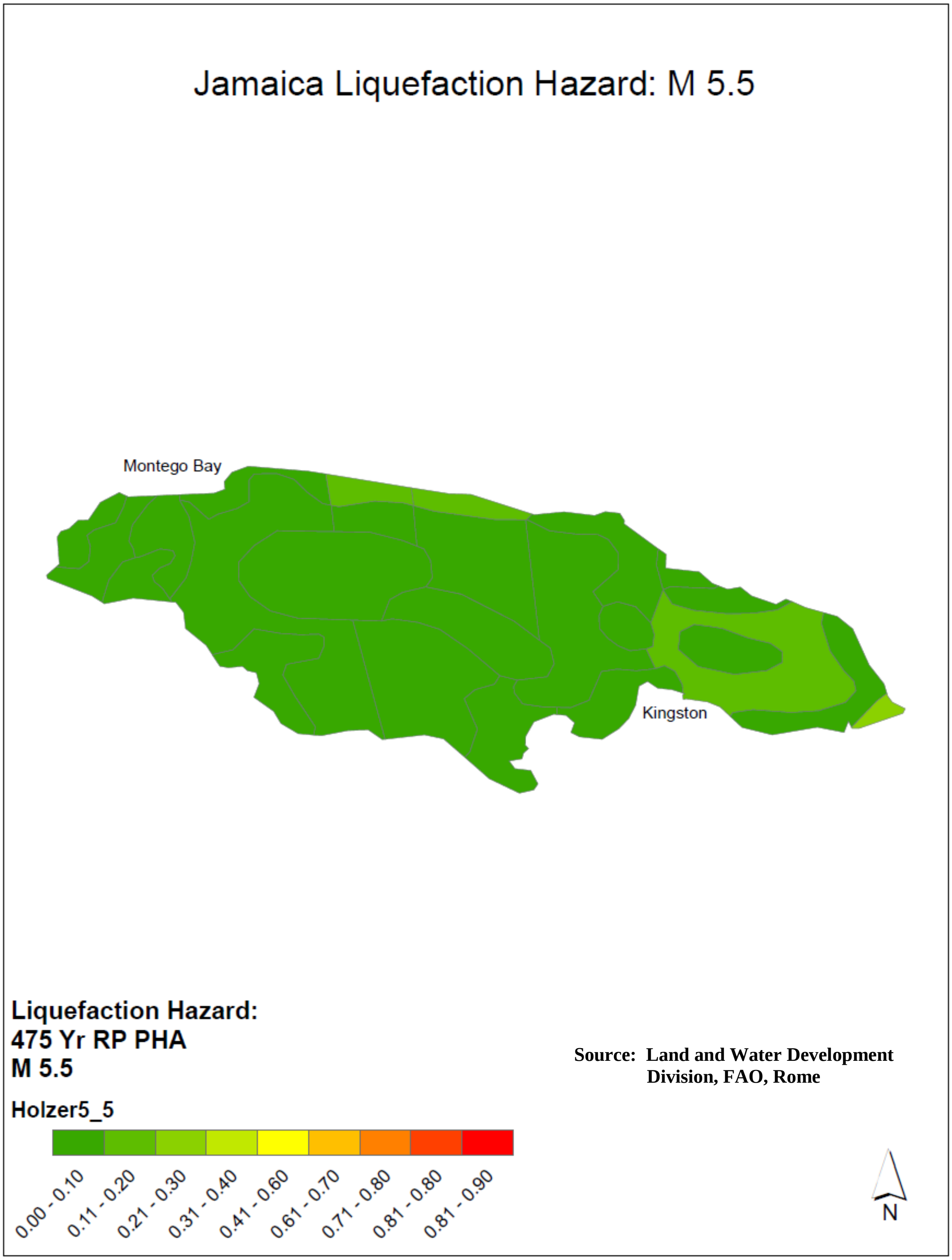

Figure 5.8 - Jamaica liquefaction hazard, M=5.5

Primary observations are from the magnitude 7.5 calculations, in which all liquefiable soils on the eastern half of the island had a probability over 31% of liquefying given the PHA at a 475 year return period. The Kingston area had a 61% probability of liquefaction, which is understandable given its considerable history with the failure mechanism. The beach ridge along the northern coast also had a very high risk of liquefaction given the high magnitude event.

As magnitude decreases, probabilities decrease rapidly for all areas with the exception of the eastern tip of Jamaica, which in addition to being a vulnerable deposit, is very close to the area designated with the highest acceleration value. However, at M=5.5 even that most vulnerable area has less than a 40% probability of liquefaction.

5.4 Trinidad

Trinidad's geologic classes are more distributed on the island than in Jamaica. The alluvial plain area had large areas of both deltas and floodplains, as expected given the application of the Youd and Perkins (1978) values shown in Chapter 4, but it should be noted that large areas, particularly in the Northern range, did not fall under a Holzer et al. (2001) classification due to the terrain. Surficial geology classification of Trinidad is shown in Figure 5.9.

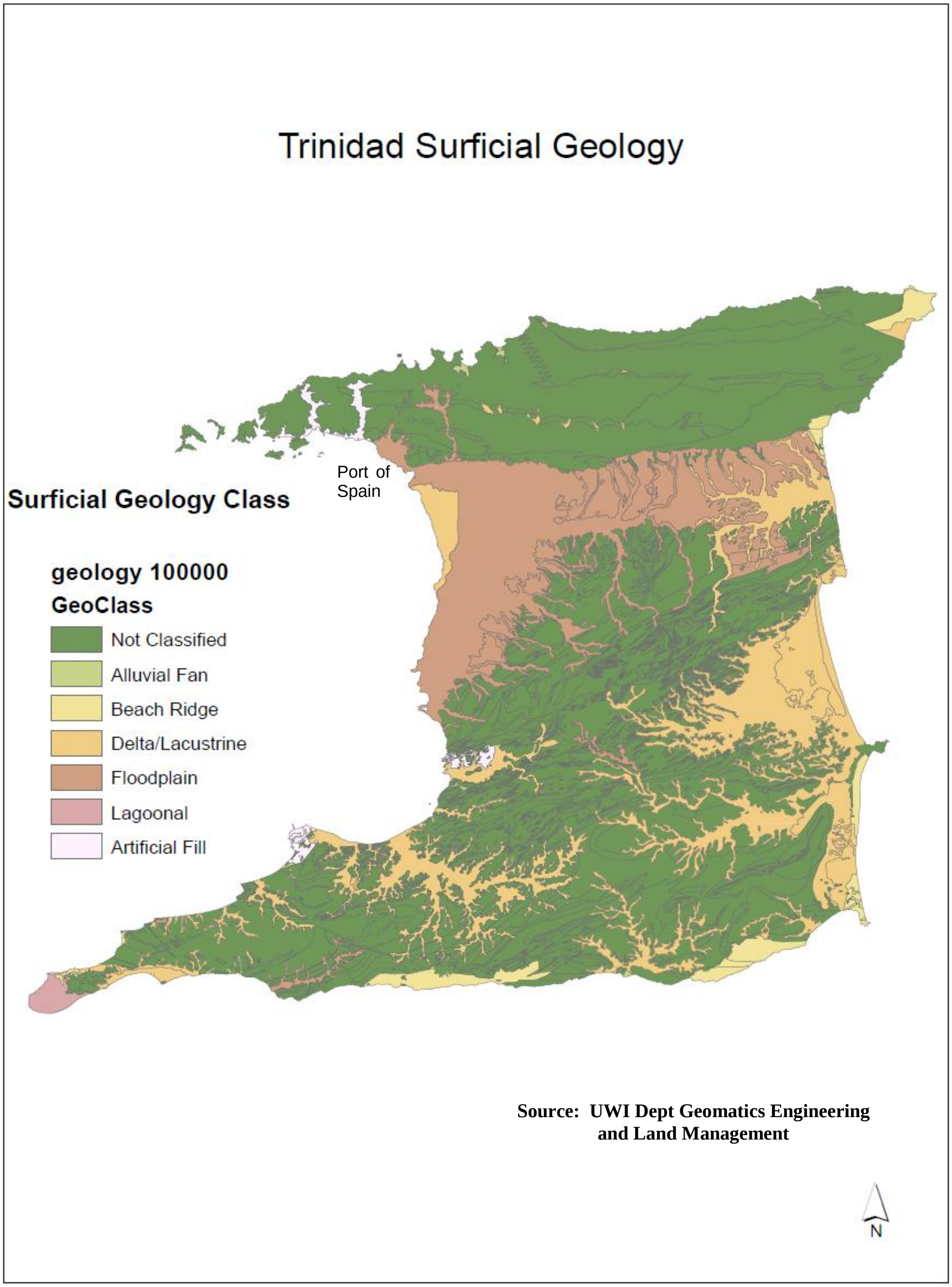

Figure 5.9 - Trinidad surficial geology classifications

Several deltas also created a larger area of hazard in the southern plains of the island. The largest areas of artificial fill were several cities on the western coast of Trinidad. Port of Spain itself was not well represented on the map as it is underlain by a very large floodplain deposit that also dominates the alluvial plain south of the northern ridge. As mentioned the coastline had numerous instances of alluvial fans, beach ridges, and lagoonal deposits that increased the liquefaction hazard. Slight discrepancies show areas where a larger geologic parcel bordered two of the PGA regions, in which case either the dominant, or in the case of equal distribution, the higher value was chosen. Six acceleration values were applied and are shown in Figure 5.10.

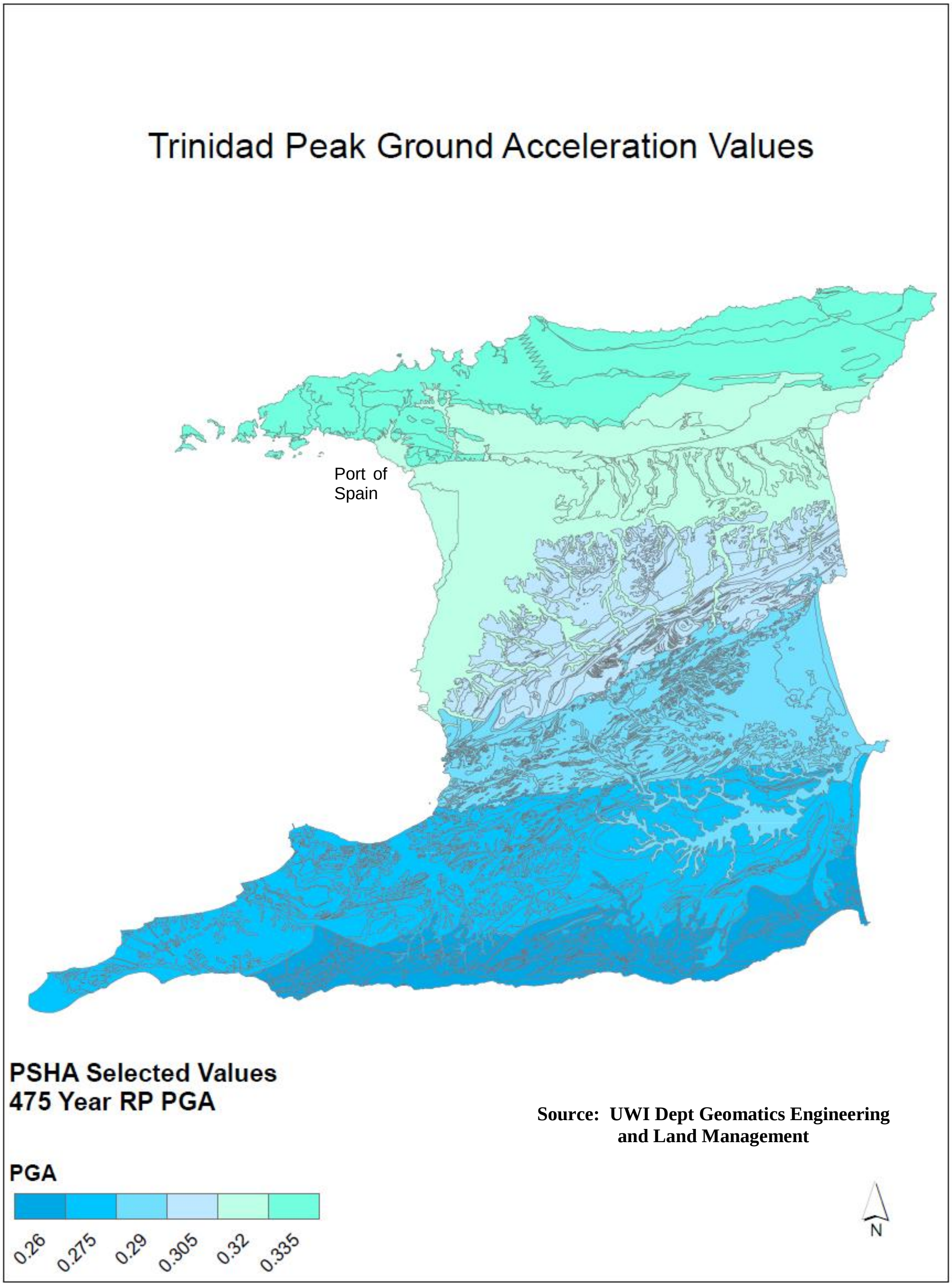

Figure 5.10 - Peak ground acceleration for Trinidad, reproduced from Bozzoni et al. (2011)

Probability varied and increased from south to north. The highest value was greater than that of Jamaica, reaching 0.335 g for a 475 year return period. By the same process as Jamaica, the values and geologic classification were used to determine hazard. The higher acceleration values and larger areas of vulnerable surficial geology have a clear effect on the probability of liquefaction during strong motion. Liquefaction hazard maps are presented from highest to lowest magnitude in Figures 5.11 through 5.15.

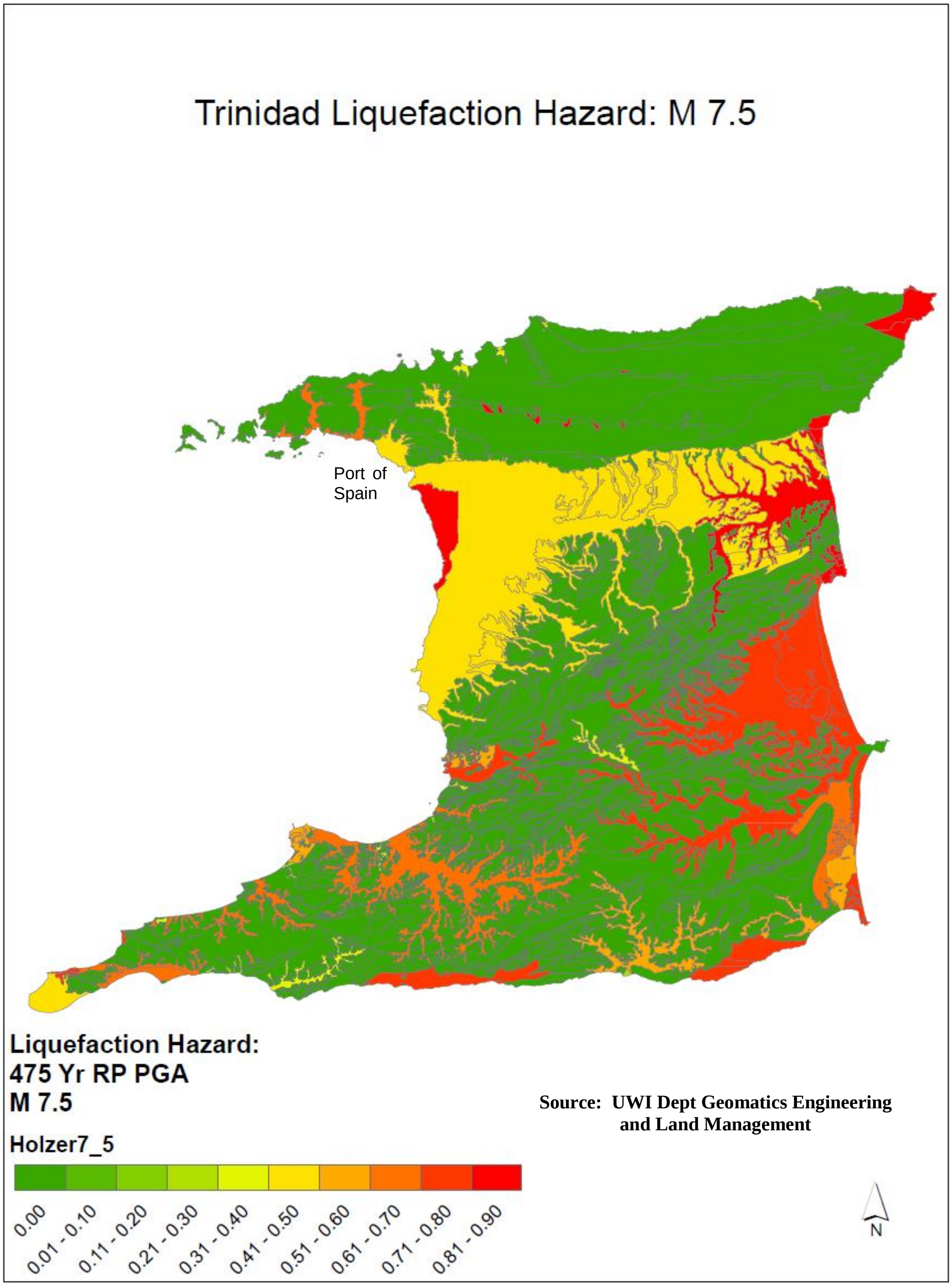

Figure 5.11 - Trinidad liquefaction hazard, M=7.5

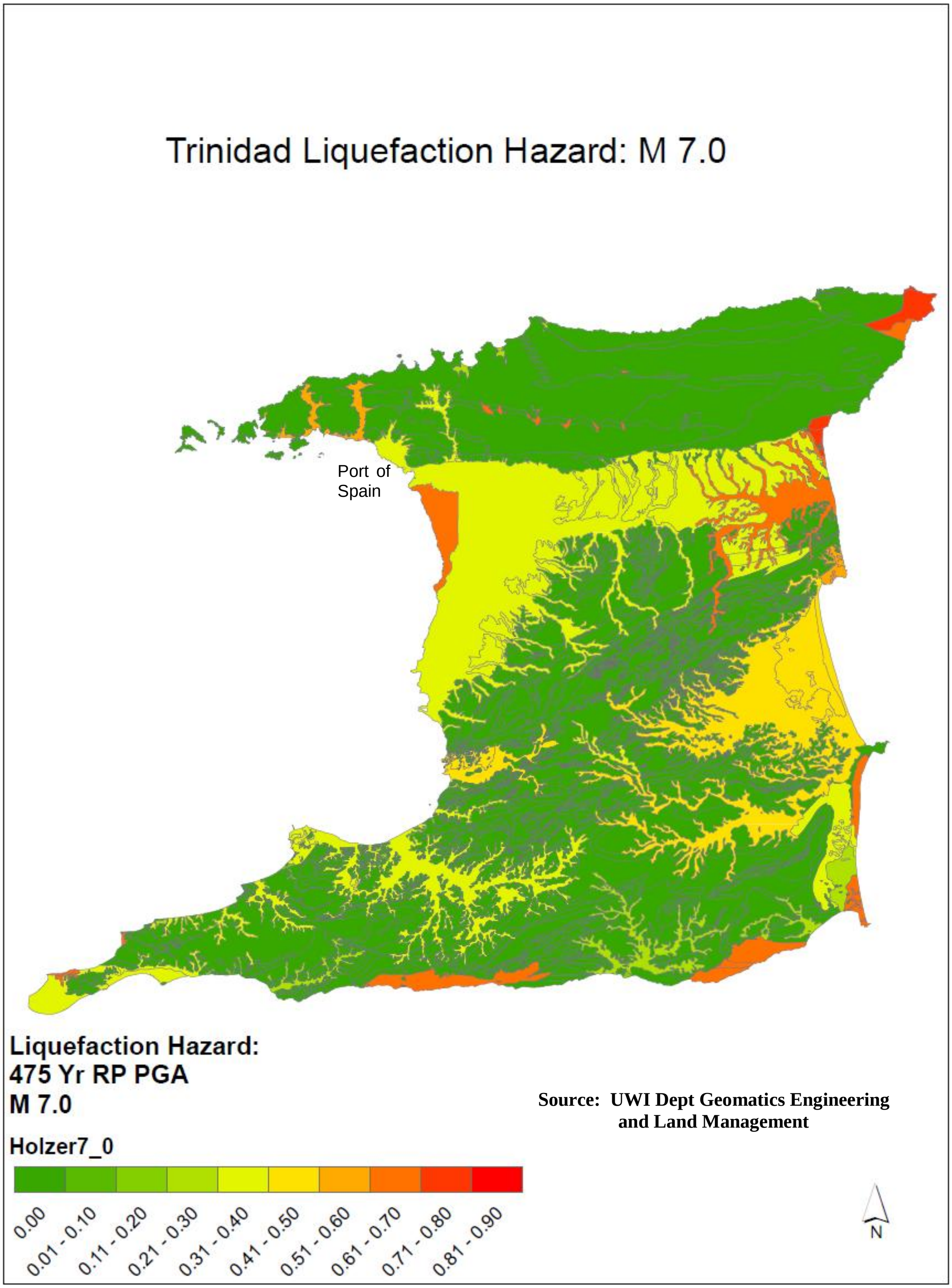

Figure 5.12 - Trinidad liquefaction hazard, M=7.0

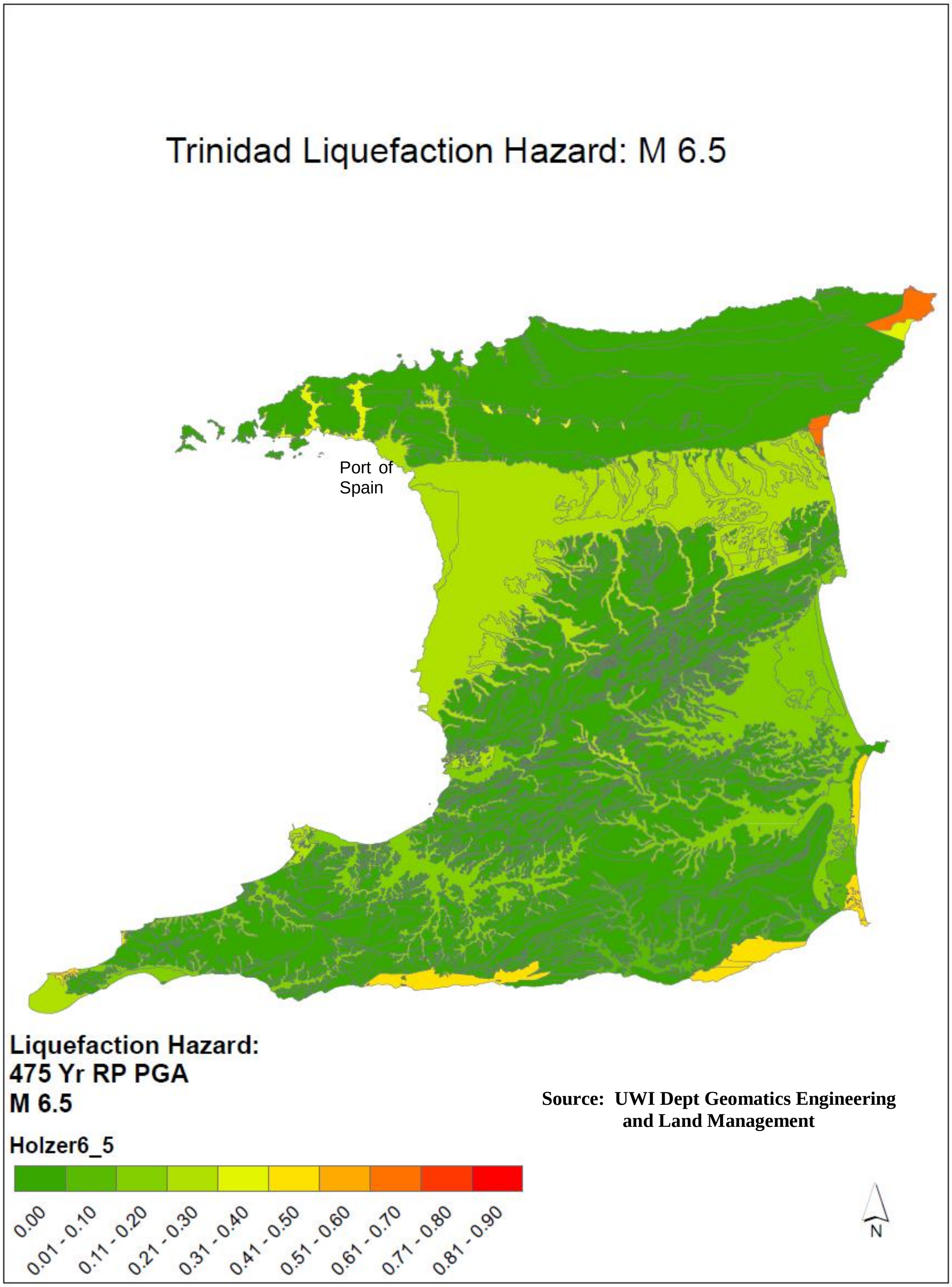

Figure 5.13 - Trinidad liquefaction hazard, M=6.5

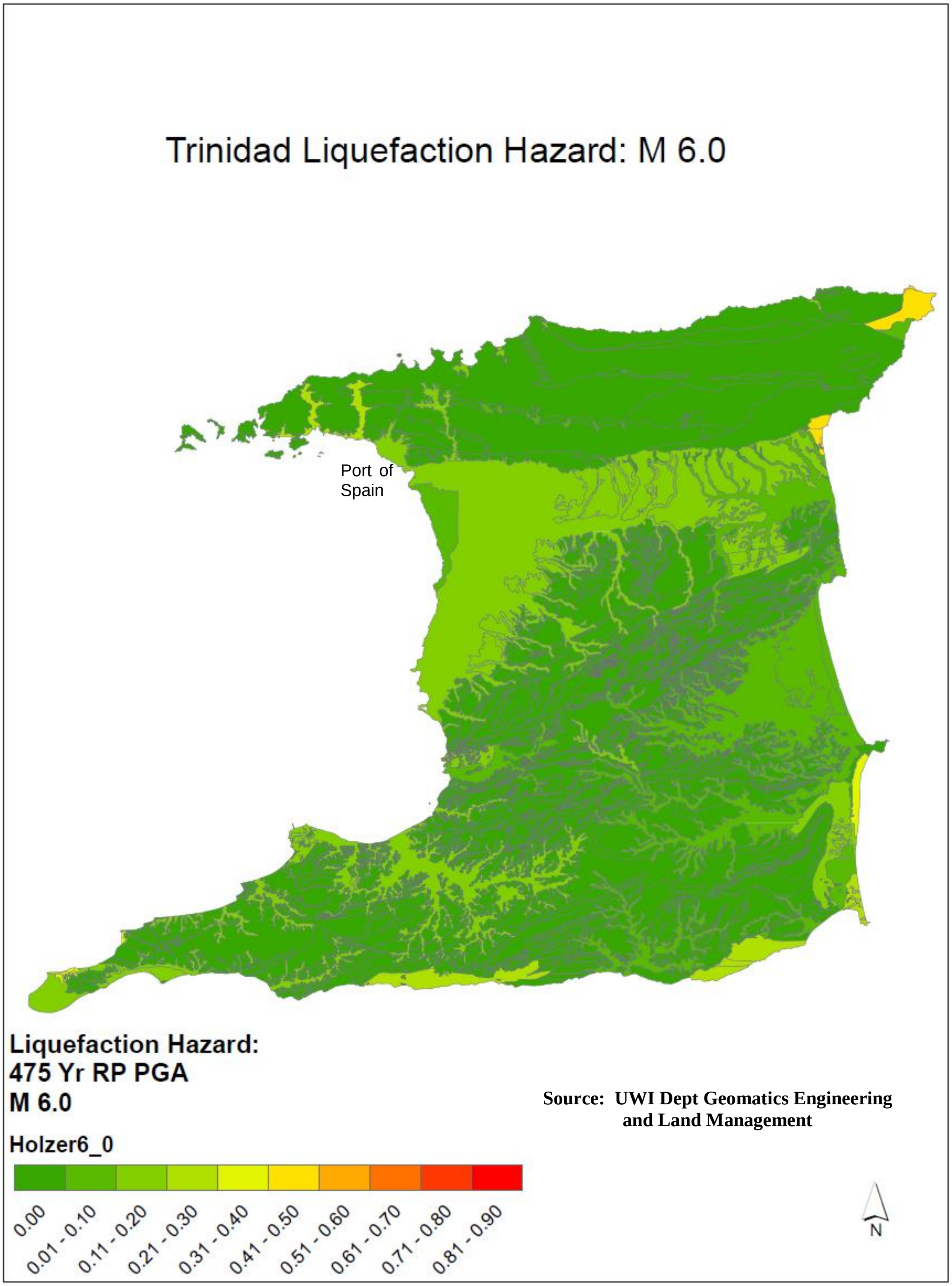

Figure 5.14 - Trinidad liquefaction hazard, M=6.0

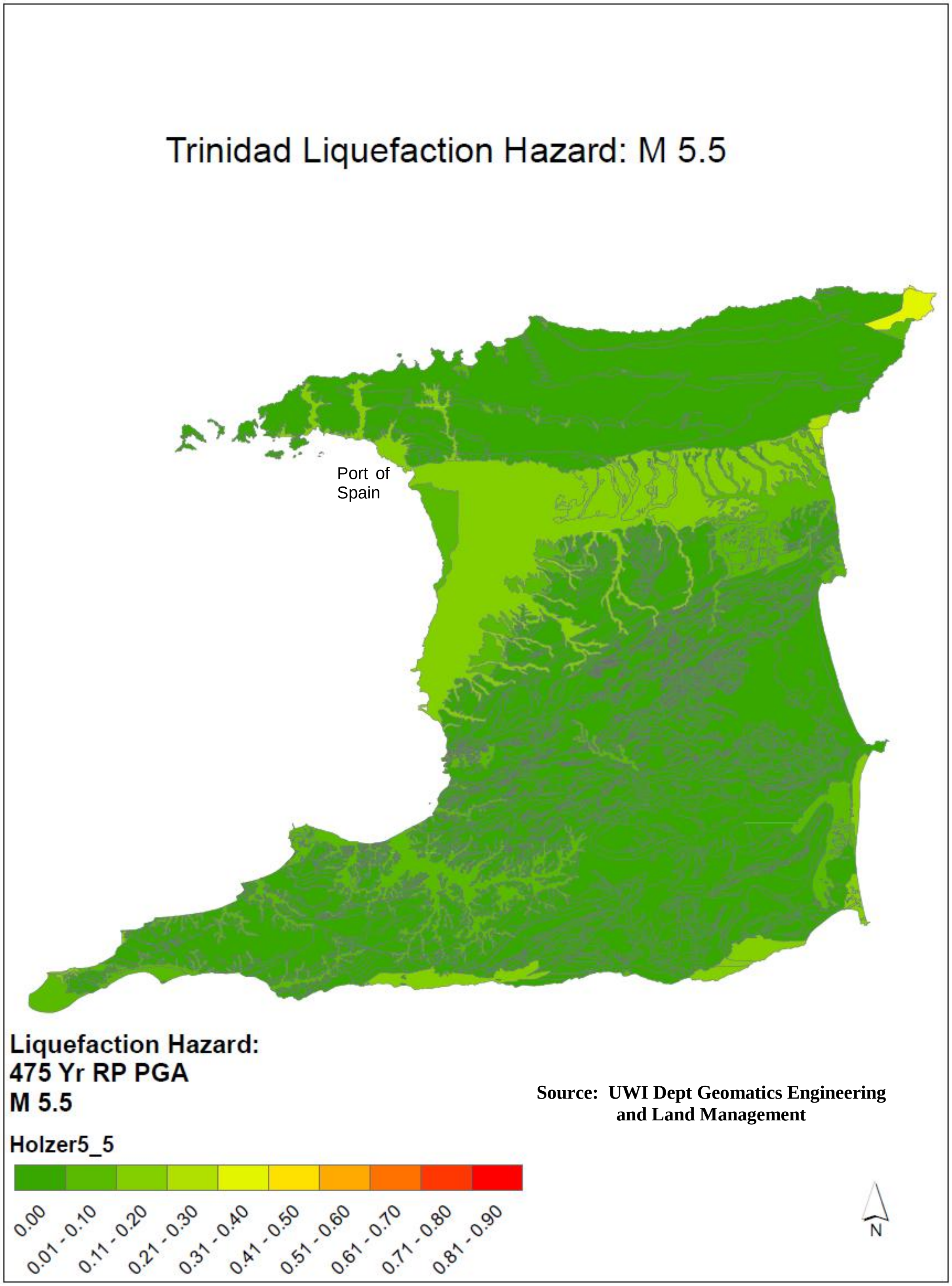

Figure 5.15 - Trinidad liquefaction hazard, M=5.5

Large portions of Trinidad are subject to liquefaction at the highest level of magnitude, many of them with probability over 60%. This high hazard includes the alluvial and deltaic deposits adjacent to Port of Spain. Given the significant nationwide potential for liquefaction type failure, this failure would be a key damage mechanism during the earthquake. Even at a magnitude of 6.5, much of the island has an elevated probability of liquefaction at the 475 year return period PGA values. With M=5.5 small parts of the island still have a greater than 20% chance of liquefaction occurring.

5.5 Summary

Given their PSHA values of acceleration and geological distributions, there is a significant hazard of liquefaction during major earthquake events on both islands. The liquefaction hazard maps presented show that coastal regions tend to have the highest probability of liquefaction for a given value of acceleration and magnitude, and that they decrease in probability the least with a given magnitude. Also, it is shown that while liquefaction is most likely during very strong (M>6.5) events, liquefaction still remains a significant hazard for parts of each island during seismic events at lower magnitude.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This thesis has developed a series of liquefaction susceptibility and hazard maps that can be applied for evaluation of hazard and risk posed to Jamaica and Trinidad by liquefaction during seismic events. This was performed by expanding two separate and independent procedures previously applied to very local liquefaction hazard maps by using GIS to manipulate large datasets describing soil and geologic characteristics over the two islands. This work exposed several trends in liquefaction due to the distribution of soil which could be applied to other islands of the Caribbean and around the world with similar geology. Liquefaction hazard at numerous magnitudes was also considered through the use of the maps to show change across a geologic area using the same PSHA values as magnitude varied. This chapter summarizes those results.

6.2 Conclusions

A wide variety of data was compiled to create easily read and used maps describing liquefaction hazard in Jamaica and Trinidad. The result was a series of easily read and utilized maps indication areas of comparably higher hazard on each of the islands. Historical data suggests that liquefaction during earthquakes will likely be a recurring effect for each of the countries.

Both of the methodologies used indicate that Jamaica and Trinidad have a significant liquefaction hazard. The prevalence of the hazard in the areas of urban development also indicates a high risk associated with liquefaction on both islands. With consideration to the differences in the structures of the islands, the highest levels of susceptibility are along the coastlines at alluvial outlets. By comparison, Trinidad had a much larger liquefiable fraction than Jamaica due to the extensive alluvial plain running east-west on the island. Jamaica's hazardous areas appear to be much more localized, but both islands would be subject to significant liquefaction effects if magnitude exceeded 6.0.

6.2.1 Jamaica

GIS data from the Digital Soils Maps of the World program was combined with PSHA and supplemental data to develop maps showing liquefiable deposits on the island of Jamaica, where liquefaction has previously been recorded with devastating effects. Qualitative susceptibility values indicate several areas of significant liquefaction vulnerability. Both the susceptibility and hazard maps indicate that the alluvial areas forming lowlands and leading into the sea have the greatest potential for liquefaction. Application of probability curves show that the eastern half of the island, particularly including the city of Kingston, has one of the highest likelihoods of liquefaction during a strong ground motion event. Examination of varying magnitudes shows that probability drops quickly with magnitude on the island.

6.2.2 Trinidad

Local sourced GIS data was employed for the development of maps indicating liquefiable deposits in the country of Trinidad. The high resolution data provided very precise identification of susceptible soil deposits, which in particular included the city of Port of Spain. Application of a recent PSHA and surficial geology classification showed that a large portion of Trinidad would be subject to liquefaction during a strong earthquake event, and that even at a magnitude of 5.5 some areas would have a moderate probability of liquefaction. Areas in Trinidad most likely to liquefy were the large delta areas forming the alluvial plains and coasts and the numerous bays along the coast of the island formed from marine deposits.

6.3 Recommendations

Liquefaction is a significant hazard in Trinidad and Jamaica and likely the remainder of the Caribbean islands. Considerations of seismic setting and the potential for liquefaction of soil should be considered explicitly during the civil engineering design process during work in these countries, particularly when work is occurring near the coast or during the use of engineered fill. Site-specific in-situ geotechnical investigations are advised for construction in these areas, in contrast to the general assessments provided for by current building codes. The same factors should be considered during emergency planning. Areas with high susceptibility to liquefaction should be avoided when possible due to the uncertainty associated with them during a significant seismic event.

More extensive research and data collection is advised for all regions susceptible to liquefaction. Use of CPT or other in-situ testing would allow for development of site specific liquefaction probability indices and curves (Toprak & Holzer, 2003; Holzer, et al., 2011). A higher resolution GIS for Jamaica would also be advised to more accurately identify higher risk soil deposits.

6.4 Application

The soil hazards levels identified are based on dominant soil types identified in the GIS data and through soil survey data identified for the island. As a result, there is an unexamined potential for localized liquefaction effects as a result of natural or manmade variability in soil deposits. Areas with a high level of fill material, particularly reclaimed land, could not be accurately evaluated in the absence of extensive in-situ testing, and are therefore assigned the highest level of hazard due to their variability. This study should not replace a site-specific soil survey with considerations for both seismic and construction loads. The two methodologies used in this study should be applied in tandem in order to avoid the limitations of either map. Port of Spain is an example in which the city fell under a geology that was less susceptible, but the fill on which it was constructed has a high susceptibility, which is shown on separate maps as they were produced here.

These values are provided only with regard specifically to liquefaction hazard, not other mechanisms of ground failure. There are significant slopes throughout Jamaica and particularly in the northern region of Trinidad. This study does not address the potential for landslide as a result of seismic activity or rainfall, both of which are significant hazards on each of the islands and should be addressed during any siting considerations as well as emergency mitigation and planning. Serious and destructive landslides have been recorded in each of the countries. As a result, it is suggested that this information be utilized as a part of an all-hazards survey that addresses other types of ground failure and other disasters in addition to seismic events.

APPENDICES

Appendix A: Soils Data

Table A.1 – Trinidad soil description and classification

Region	Group	Soil #	Soil Name	Lithology	Drainage	Description	YP
Soils of the alluvial plains and valleys	A1	1	Cocal Sand	Beach Sand	free	Deep cultivated beach sand with free internal drainage	Very High
		101	San Quintin Sand	sand	free		Very High
		201	Granville Sand	sand	free		Very High
		2/L	Icacos sand	sand	free		Very High
	A2	7	Savaneta Clay	Clay on Sand	impeded	deep hydromorphic soil with restricted internal drainage	High
		9	Bejucal Clay	Swamp Clay	impeded		Low
		109	Bois Neuf Clay	Swamp Clay	impeded		Low
		209	Brighton clay	Swamp Clay	impeded		Low
		309	Cacandee Clay	Swamp Clay	impeded		Low
		409	Frederic Clay	Swamp Clay	impeded		Low
		509	La Fortune Clay	Swamp Clay	impeded		Low
		609	San Francique Clay	Swamp Clay	impeded		Low
		11	Brazil Peaty Sand	Peat on sand	impeded		high
		15	Caroni Peaty Clay	Peaty Clay	impeded		high
		115	Godineau clay	peat and clay	impeded		Low
		215	Macaw Peaty Clay	Peaty Clay	impeded		Low
		315	Nariva Peaty Clay	Peaty Clay	impeded		Low
		17	Barataria Peat	Peat	impeded		Low
		12	Caroni Peaty Clay	Peat on clay	impeded		Moderate
	A3	21	Poui series	sand	free	Deep Alluvial soils with free internal drainage	High
		121	McBean series	Sand	free		High
		221	Washington Series	Sand	free		High
		23	Golden Grove Series	Schistose detritus	free		High
		123	Guanapo Series	Micaceous Sand, Gravel	free		High
		223	River Estate Series	Micaceous phyllites, sand	free		Moderate
		323	St. Joseph Series	Micaceous Riverwash	free		Moderate
		423	Tacarigua Series	Micaceous loam	free		Moderate
		24/L	Grande Riviere Series	Mixed calcareous carbonaceous schist alluvium	free		High
		25	Mahaut Series	sandy clay alluvium	free		High
		125	Schooners series	sandy clay alluvium	free		High
	A4	31	St. John Series	sandy alluvium	imperfect	Deep alluvial soils with restricted internal drainage	High
		131	Freeport Series	sandy clay alluvium	imperfect		moderate
		231	Couva Series	sandy clay alluvium	imperfect		high
		331	Orange Grove Series	sandy clay alluvium	imperfect		high
		431	Erin River series	sandy clay alluvium	imperfect		moderate
		32/L	Caracas Clay	calcareous clay on sand	imperfect		high
		33	Cunupia Series	silty clay alluvium	imperfect		Moderate
		133	Oropouche Series	silty clay alluvium	imperfect		Moderate
		233	Sangre Grande Series	silty clay alluvium	imperfect		high
		333	Pasea Series	silty clay alluvium	imperfect		High
		35	L'Ebranche Series	clay alluvium	imperfect		Moderate
		135	Waterloo Series	clay alluvium	imperfect		Moderate
		235	Galpha Series	clay alluvium	imperfect		Moderate
		335	Sevilla Clay	clay alluvium	imperfect		Moderate
		435	St. James Clay	clay alluvium	imperfect		Moderate
		37	Aranguez Series	silty clay alluvium	impeded		Moderate
		39	Navet Clay	clayey alluvium	impeded		Very High
		139	Cromarty Clay	clay alluvium	impeded		moderate
		239	Debe Clay	clay alluvium	impeded		moderate
		339	Columbia Clay	clay alluvium	impeded		moderate

Table A.1 Continued

Region	Group	Soil #	Soil Name	Lithology	Drainage	Description	YP
Soils of the terraces and subsidary ranges	B1	41	blanchisseuse series	micaceous phyllites,	free	terrace soils with free internal drainage	Moderate
		141	galera sand	quartzitic gravels and sands	free		Moderate
		241	Las Lomas series	levee sand	free		Moderate
		43	Acono series	micaceous (bouldery) colluvia	free		Low
		143	St. Augustine series	micaceous colluvia	free		Low
		243	Santa Cruz series	micaceous colluvia (with limestone association)	free		Low
		45	Austin Series	sandy shale	free		Moderate
		145	Carapal Series	sandy shale	free		Moderate
		245	Avocat Series	sandy clay shale	free		Low
		49	Non Pariel Series	porcellanite	free		Low
	B2	51	Aripo Sand	sand	imperfect	Terrace soils with restricted internal drainage	Moderate
		151	Macoya Series	sand	imperfect		high
		53	Anglais series	micaceous phyllites, quartz, sandstone	free		Moderate
		153	cleaver series	loamy hillwash	free		Moderate
		253	streatham series	micaceous sandy hillwash	imperfect		Low
		55	Piarco series	sand and gravel	imperfect		Moderate
		155	Phoenix Series	sand and clay	imperfect		Moderate
		255	Valencia series	clayey sand and gravel	imperfect		High
		59	Long Stretch Series	Clay	imperfect		Low
		159	Oropuna Series	clay	impeded		Low
	C1	61	Delhi Series	sandy shale	free	Soils of the intermediate uplands with free internal drainage	Moderate
		161	Antilles series	sand	free		Moderate
		261	Arena Sand	sand	free		Moderate
		361	Siparia Sand	sand	free		Moderate
		461	Chatham series	sand	free		Moderate
		63	Mayaro Sand	sandstone	free		Moderate
		68/L	Montserrat Series	Glauconitic Sandstone	free		low

Table A.1 Continued

Region	Group	Soil #	Soil Name	Lithology	Drainage	Description	YP
Soils of the Uplands	C2	71	Mt. Harris Series	sandstone	imperfect	soils of the intermediate uplands with restricted internal drainage	low
		72/L	Rock Road Series	calcareous clay and sand	imperfect		low
		74/L	Piparo Series	volcanic mudfloy	imperfect		low
		174/L	Green Hill Series	calcarous clay and sand	imperfect		low
		274/L	Morne Diablo Series	calcareous volcanic mudflow	imperfect		low
		374/L	perseverance series	calcareous volcanic mudflow	imperfect		low
		474/L	Princes Town clay	marl	imperfect		low
		574/L	Biche Clay	Marl	imperfect		low
		674/L	Brasso Clay	calcareous siltstone	imperfect		low
		75	St. Maries Series	sandy clay shale	imperfect		low
		175	cedros series	sandy clay shale	imperfect		low
		275	Rochard Series	sandy clay shale	imperfect		low
		375	Saunders Road Series	sandy clay shale	imperfect		low
		475	La Retraite series	sandy clay shale	imperfect		low
		575	Mourga Series	mixed shale	imperfect		low
		675	Mitan Seires	silty shale	imperfect		low
		775	Buenos Aires series	clay shale	imperfect		low
		875	Chaudiere Series	clay shale	imperfect		low
		975	Guayaguayare Series	clay shale	imperfect		low
		1075	Bois Bourg Series	clay	imperfect		low
		1175	La Brea Series	clay shale and sand	imperfect		low
		1275	Cap-de-Ville Series	clay shale and sand	imperfect		low
		1375	Point d'Or series	clay shale and sand	imperfect		low
		76/L	Marper Series	chloritic shale	imperfect		low
		176/L	canterbury series	graphitic shale	imperfect		low
		276/L	Quinam Series	calcarous shale	imperfect		low
		77	Ecclesville series	clay shale	impeded		low
		177	Talparo Series	clay	impeded		low
		277	Bel Air Series	clay shale	impeded		low
		377	Marac series	clay shale	impeded		low
		178	Chickland series	shelly clay	impeded		low
		78/L	Basseterre Series	calcareous volcanic mudflow	imperfect		low
		178/L	Chickland series	shaley clay	impeded		low
		278/L	Tarouba Series	calcareous clay shale	impeded		low
	C3	81	Maracas series	micaceous phyllites	free	High upland soils with free internal drainage	Low
		181	Matelot series	micaceous phyllites	free		Low
		281	Spring hill series	micaceous phyllites, talc	free		Low
		381	San Fernando Sand	argillite	free		Low
		82/L	Diego Martin Series	calcareous phyllites and limestone	free		Low
		182/L	La Pastora Series	Limestone	free		Low
		282/L	Maraval Series	Limestone	free		Low
		382/L	Platanal	Limestone	free		Low
		482/L	Tamana Clay	Limestone	free		Low
	C4	91	Sans Souci Series	Igneous Rock	imperfect	High upland soils with restricted internal drainage	Low
		94/L	Toco Series	Mixed calcarous and carbonaceous phyllites	imperfect		Low

Appendix B: Probability Values

Table B.1 - Probability values M=7.5

Magnitude		7.5	Constant values from Holzer, et al. (2011)				
MSF		0.999638941					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.005	0.005	0.00	0.00	0.00	0.00	0.00	0.00
0.01	0.010	0.00	0.00	0.00	0.00	0.00	0.00
0.015	0.015	0.00	0.00	0.00	0.00	0.00	0.00
0.02	0.020	0.00	0.00	0.00	0.00	0.00	0.00
0.025	0.025	0.00	0.00	0.00	0.00	0.00	0.00
0.03	0.030	0.00	0.00	0.00	0.00	0.00	0.00
0.035	0.035	0.00	0.00	0.00	0.00	0.00	0.00
0.04	0.040	0.00	0.00	0.00	0.00	0.00	0.00
0.045	0.045	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.050	0.00	0.01	0.00	0.00	0.00	0.00
0.055	0.055	0.00	0.01	0.00	0.01	0.00	0.00
0.06	0.060	0.00	0.01	0.00	0.01	0.00	0.00
0.065	0.065	0.00	0.02	0.00	0.01	0.00	0.00
0.07	0.070	0.00	0.02	0.00	0.01	0.00	0.00
0.075	0.075	0.00	0.03	0.00	0.01	0.00	0.00
0.08	0.080	0.00	0.04	0.00	0.02	0.01	0.01
0.085	0.085	0.01	0.04	0.00	0.02	0.01	0.01
0.09	0.090	0.01	0.06	0.00	0.02	0.01	0.01
0.095	0.095	0.01	0.07	0.00	0.03	0.01	0.01
0.1	0.100	0.01	0.08	0.00	0.03	0.02	0.02
0.105	0.105	0.01	0.10	0.00	0.04	0.02	0.02
0.11	0.110	0.01	0.11	0.00	0.04	0.02	0.02
0.115	0.115	0.02	0.13	0.00	0.05	0.03	0.03
0.12	0.120	0.02	0.15	0.00	0.06	0.04	0.03
0.125	0.125	0.02	0.17	0.00	0.07	0.04	0.04
0.13	0.130	0.03	0.19	0.00	0.07	0.05	0.05
0.135	0.135	0.03	0.22	0.01	0.08	0.06	0.06
0.14	0.140	0.04	0.24	0.01	0.09	0.07	0.07
0.145	0.145	0.04	0.26	0.01	0.10	0.08	0.08
0.15	0.150	0.05	0.29	0.01	0.11	0.09	0.09
0.155	0.155	0.05	0.32	0.02	0.12	0.10	0.10
0.16	0.160	0.06	0.34	0.02	0.13	0.11	0.12
0.165	0.165	0.06	0.37	0.03	0.14	0.13	0.13
0.17	0.170	0.07	0.40	0.04	0.15	0.14	0.15
0.175	0.175	0.08	0.42	0.05	0.16	0.16	0.17
0.18	0.180	0.08	0.45	0.06	0.17	0.17	0.19
0.185	0.185	0.09	0.47	0.07	0.18	0.19	0.20
0.19	0.190	0.10	0.50	0.09	0.19	0.20	0.22
0.195	0.195	0.11	0.52	0.11	0.20	0.22	0.24
0.2	0.200	0.12	0.54	0.13	0.22	0.24	0.26
0.205	0.205	0.13	0.57	0.15	0.23	0.26	0.28
0.21	0.210	0.14	0.59	0.18	0.24	0.28	0.30
0.215	0.215	0.15	0.61	0.21	0.25	0.29	0.32

Table B.1 Continued

Magnitude		7.5	Constant values from Holzer, et al. (2011)				
MSF		0.999638941					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.22	0.220	0.16	0.63	0.24	0.26	0.31	0.35
0.225	0.225	0.17	0.64	0.27	0.27	0.33	0.37
0.23	0.230	0.18	0.66	0.31	0.28	0.35	0.39
0.235	0.235	0.19	0.68	0.35	0.29	0.37	0.41
0.24	0.240	0.20	0.69	0.39	0.30	0.38	0.42
0.245	0.245	0.21	0.71	0.43	0.31	0.40	0.44
0.25	0.250	0.22	0.72	0.47	0.32	0.42	0.46
0.255	0.255	0.23	0.74	0.50	0.33	0.43	0.48
0.26	0.260	0.24	0.75	0.54	0.34	0.45	0.50
0.265	0.265	0.25	0.76	0.58	0.35	0.46	0.51
0.27	0.270	0.27	0.77	0.61	0.36	0.48	0.53
0.275	0.275	0.28	0.78	0.65	0.37	0.49	0.54
0.28	0.280	0.29	0.79	0.68	0.38	0.50	0.55
0.285	0.285	0.30	0.80	0.71	0.38	0.52	0.57
0.29	0.290	0.31	0.81	0.73	0.39	0.53	0.58
0.295	0.295	0.32	0.82	0.76	0.40	0.54	0.59
0.3	0.300	0.33	0.82	0.78	0.41	0.55	0.60
0.305	0.305	0.34	0.83	0.80	0.41	0.56	0.61
0.31	0.310	0.35	0.84	0.82	0.42	0.57	0.62
0.315	0.315	0.36	0.84	0.83	0.43	0.58	0.63
0.32	0.320	0.37	0.85	0.85	0.43	0.59	0.64
0.325	0.325	0.38	0.85	0.86	0.44	0.60	0.65
0.33	0.330	0.39	0.86	0.87	0.44	0.61	0.66
0.335	0.335	0.40	0.86	0.88	0.45	0.62	0.66
0.34	0.340	0.40	0.87	0.89	0.46	0.62	0.67
0.345	0.345	0.41	0.87	0.90	0.46	0.63	0.68
0.35	0.350	0.42	0.88	0.91	0.47	0.64	0.68
0.355	0.355	0.43	0.88	0.92	0.47	0.64	0.69
0.36	0.360	0.44	0.88	0.92	0.47	0.65	0.69
0.365	0.365	0.44	0.89	0.93	0.48	0.65	0.70
0.37	0.370	0.45	0.89	0.93	0.48	0.66	0.70
0.375	0.375	0.46	0.89	0.94	0.49	0.66	0.71
0.38	0.380	0.46	0.90	0.94	0.49	0.67	0.71
0.385	0.385	0.47	0.90	0.94	0.49	0.67	0.72
0.39	0.390	0.48	0.90	0.95	0.50	0.68	0.72
0.395	0.395	0.48	0.90	0.95	0.50	0.68	0.72
0.4	0.400	0.49	0.91	0.95	0.51	0.68	0.73
0.405	0.405	0.50	0.91	0.95	0.51	0.69	0.73
0.41	0.410	0.50	0.91	0.96	0.51	0.69	0.73
0.415	0.415	0.51	0.91	0.96	0.51	0.69	0.73
0.42	0.420	0.51	0.91	0.96	0.52	0.70	0.74
0.425	0.425	0.52	0.92	0.96	0.52	0.70	0.74
0.43	0.430	0.52	0.92	0.96	0.52	0.70	0.74

Table B.1 Continued

Magnitude		7.5	Constant values from Holzer, et al. (2011)				
MSF		0.999638941					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.435	0.435	0.52	0.92	0.96	0.53	0.70	0.74
0.44	0.440	0.53	0.92	0.96	0.53	0.71	0.75
0.445	0.445	0.53	0.92	0.97	0.53	0.71	0.75
0.45	0.450	0.54	0.92	0.97	0.53	0.71	0.75
0.455	0.455	0.54	0.92	0.97	0.53	0.71	0.75
0.46	0.460	0.54	0.93	0.97	0.54	0.71	0.75
0.465	0.465	0.55	0.93	0.97	0.54	0.72	0.75
0.47	0.470	0.55	0.93	0.97	0.54	0.72	0.75
0.475	0.475	0.55	0.93	0.97	0.54	0.72	0.76
0.48	0.480	0.56	0.93	0.97	0.54	0.72	0.76
0.485	0.485	0.56	0.93	0.97	0.55	0.72	0.76
0.49	0.490	0.56	0.93	0.97	0.55	0.72	0.76
0.495	0.495	0.57	0.93	0.97	0.55	0.72	0.76
0.5	0.500	0.57	0.93	0.97	0.55	0.73	0.76
0.505	0.505	0.57	0.93	0.97	0.55	0.73	0.76
0.51	0.510	0.57	0.93	0.97	0.55	0.73	0.76
0.515	0.515	0.58	0.94	0.97	0.56	0.73	0.76
0.52	0.520	0.58	0.94	0.97	0.56	0.73	0.77
0.525	0.525	0.58	0.94	0.97	0.56	0.73	0.77
0.53	0.530	0.58	0.94	0.97	0.56	0.73	0.77
0.535	0.535	0.59	0.94	0.97	0.56	0.73	0.77
0.54	0.540	0.59	0.94	0.97	0.56	0.73	0.77
0.545	0.545	0.59	0.94	0.97	0.56	0.73	0.77
0.55	0.550	0.59	0.94	0.97	0.56	0.73	0.77
0.555	0.555	0.59	0.94	0.97	0.56	0.74	0.77
0.56	0.560	0.60	0.94	0.97	0.57	0.74	0.77
0.565	0.565	0.60	0.94	0.97	0.57	0.74	0.77
0.57	0.570	0.60	0.94	0.97	0.57	0.74	0.77
0.575	0.575	0.60	0.94	0.97	0.57	0.74	0.77
0.58	0.580	0.60	0.94	0.97	0.57	0.74	0.77
0.585	0.585	0.60	0.94	0.97	0.57	0.74	0.77
0.59	0.590	0.60	0.94	0.97	0.57	0.74	0.77
0.595	0.595	0.61	0.94	0.97	0.57	0.74	0.77
0.6	0.600	0.61	0.94	0.97	0.57	0.74	0.77
0.605	0.605	0.61	0.94	0.98	0.57	0.74	0.77
0.61	0.610	0.61	0.94	0.98	0.57	0.74	0.77
0.615	0.615	0.61	0.94	0.98	0.57	0.74	0.77
0.62	0.620	0.61	0.94	0.98	0.58	0.74	0.77
0.625	0.625	0.61	0.95	0.98	0.58	0.74	0.78
0.63	0.630	0.61	0.95	0.98	0.58	0.74	0.78
0.635	0.635	0.62	0.95	0.98	0.58	0.74	0.78
0.64	0.640	0.62	0.95	0.98	0.58	0.74	0.78
0.645	0.645	0.62	0.95	0.98	0.58	0.74	0.78

Table B.1 Continued

Magnitude		7.5	Constant values from Holzer, et al. (2011)				
MSF		0.999638941					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.65	0.650	0.62	0.95	0.98	0.58	0.74	0.78
0.655	0.655	0.62	0.95	0.98	0.58	0.74	0.78
0.66	0.660	0.62	0.95	0.98	0.58	0.75	0.78
0.665	0.665	0.62	0.95	0.98	0.58	0.75	0.78
0.67	0.670	0.62	0.95	0.98	0.58	0.75	0.78
0.675	0.675	0.62	0.95	0.98	0.58	0.75	0.78
0.68	0.680	0.62	0.95	0.98	0.58	0.75	0.78
0.685	0.685	0.62	0.95	0.98	0.58	0.75	0.78
0.69	0.690	0.62	0.95	0.98	0.58	0.75	0.78
0.695	0.695	0.62	0.95	0.98	0.58	0.75	0.78
0.7	0.700	0.63	0.95	0.98	0.58	0.75	0.78
0.705	0.705	0.63	0.95	0.98	0.58	0.75	0.78
0.71	0.710	0.63	0.95	0.98	0.58	0.75	0.78
0.715	0.715	0.63	0.95	0.98	0.58	0.75	0.78
0.72	0.720	0.63	0.95	0.98	0.59	0.75	0.78
0.725	0.725	0.63	0.95	0.98	0.59	0.75	0.78
0.73	0.730	0.63	0.95	0.98	0.59	0.75	0.78
0.735	0.735	0.63	0.95	0.98	0.59	0.75	0.78
0.74	0.740	0.63	0.95	0.98	0.59	0.75	0.78
0.745	0.745	0.63	0.95	0.98	0.59	0.75	0.78
0.75	0.750	0.63	0.95	0.98	0.59	0.75	0.78
0.755	0.755	0.63	0.95	0.98	0.59	0.75	0.78
0.76	0.760	0.63	0.95	0.98	0.59	0.75	0.78
0.765	0.765	0.63	0.95	0.98	0.59	0.75	0.78
0.77	0.770	0.63	0.95	0.98	0.59	0.75	0.78
0.775	0.775	0.63	0.95	0.98	0.59	0.75	0.78
0.78	0.780	0.63	0.95	0.98	0.59	0.75	0.78
0.785	0.785	0.63	0.95	0.98	0.59	0.75	0.78
0.79	0.790	0.63	0.95	0.98	0.59	0.75	0.78
0.795	0.795	0.63	0.95	0.98	0.59	0.75	0.78
0.8	0.800	0.64	0.95	0.98	0.59	0.75	0.78
0.805	0.805	0.64	0.95	0.98	0.59	0.75	0.78
0.81	0.810	0.64	0.95	0.98	0.59	0.75	0.78
0.815	0.815	0.64	0.95	0.98	0.59	0.75	0.78
0.82	0.820	0.64	0.95	0.98	0.59	0.75	0.78
0.825	0.825	0.64	0.95	0.98	0.59	0.75	0.78
0.83	0.830	0.64	0.95	0.98	0.59	0.75	0.78
0.835	0.835	0.64	0.95	0.98	0.59	0.75	0.78
0.84	0.840	0.64	0.95	0.98	0.59	0.75	0.78
0.845	0.845	0.64	0.95	0.98	0.59	0.75	0.78
0.85	0.850	0.64	0.95	0.98	0.59	0.75	0.78
0.855	0.855	0.64	0.95	0.98	0.59	0.75	0.78
0.86	0.860	0.64	0.95	0.98	0.59	0.75	0.78

Table B.1 Continued

Magnitude		7.5	Constant values from Holzer, et al. (2011)				
MSF		0.999638941					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.865	0.865	0.64	0.95	0.98	0.59	0.75	0.78
0.87	0.870	0.64	0.95	0.98	0.59	0.75	0.78
0.875	0.875	0.64	0.95	0.98	0.59	0.75	0.78
0.88	0.880	0.64	0.95	0.98	0.59	0.75	0.78
0.885	0.885	0.64	0.95	0.98	0.59	0.75	0.78
0.89	0.890	0.64	0.95	0.98	0.59	0.75	0.78
0.895	0.895	0.64	0.95	0.98	0.59	0.75	0.78
0.9	0.900	0.64	0.95	0.98	0.59	0.75	0.78
0.905	0.905	0.64	0.95	0.98	0.59	0.75	0.78
0.91	0.910	0.64	0.95	0.98	0.59	0.75	0.78
0.915	0.915	0.64	0.95	0.98	0.59	0.75	0.78
0.92	0.920	0.64	0.95	0.98	0.59	0.75	0.78
0.925	0.925	0.64	0.95	0.98	0.59	0.75	0.78
0.93	0.930	0.64	0.95	0.98	0.59	0.75	0.78
0.935	0.935	0.64	0.95	0.98	0.59	0.75	0.78
0.94	0.940	0.64	0.95	0.98	0.59	0.75	0.78
0.945	0.945	0.64	0.95	0.98	0.59	0.75	0.78
0.95	0.950	0.64	0.95	0.98	0.59	0.75	0.78
0.955	0.955	0.64	0.95	0.98	0.59	0.75	0.78
0.96	0.960	0.64	0.95	0.98	0.60	0.75	0.78
0.965	0.965	0.64	0.95	0.98	0.60	0.75	0.78
0.97	0.970	0.64	0.95	0.98	0.60	0.75	0.78
0.975	0.975	0.64	0.95	0.98	0.60	0.75	0.78
0.98	0.980	0.64	0.95	0.98	0.60	0.75	0.78
0.985	0.985	0.64	0.95	0.98	0.60	0.75	0.78
0.99	0.990	0.64	0.95	0.98	0.60	0.75	0.78
0.995	0.995	0.64	0.95	0.98	0.60	0.75	0.78
1	1.000	0.64	0.95	0.98	0.60	0.75	0.78

Table B.2 - Probability values M=7.0

Magnitude		7	Constant values from Holzer, et al. (2011)				
MSF		1.19274888					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.005	0.004	0.00	0.00	0.00	0.00	0.00	0.00
0.01	0.008	0.00	0.00	0.00	0.00	0.00	0.00
0.015	0.013	0.00	0.00	0.00	0.00	0.00	0.00
0.02	0.017	0.00	0.00	0.00	0.00	0.00	0.00
0.025	0.021	0.00	0.00	0.00	0.00	0.00	0.00
0.03	0.025	0.00	0.00	0.00	0.00	0.00	0.00
0.035	0.029	0.00	0.00	0.00	0.00	0.00	0.00
0.04	0.034	0.00	0.00	0.00	0.00	0.00	0.00
0.045	0.038	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.042	0.00	0.00	0.00	0.00	0.00	0.00
0.055	0.046	0.00	0.00	0.00	0.00	0.00	0.00
0.06	0.050	0.00	0.01	0.00	0.00	0.00	0.00
0.065	0.054	0.00	0.01	0.00	0.00	0.00	0.00
0.07	0.059	0.00	0.01	0.00	0.01	0.00	0.00
0.075	0.063	0.00	0.01	0.00	0.01	0.00	0.00
0.08	0.067	0.00	0.02	0.00	0.01	0.00	0.00
0.085	0.071	0.00	0.02	0.00	0.01	0.00	0.00
0.09	0.075	0.00	0.03	0.00	0.01	0.00	0.00
0.095	0.080	0.00	0.04	0.00	0.02	0.01	0.01
0.1	0.084	0.01	0.04	0.00	0.02	0.01	0.01
0.105	0.088	0.01	0.05	0.00	0.02	0.01	0.01
0.11	0.092	0.01	0.06	0.00	0.03	0.01	0.01
0.115	0.096	0.01	0.07	0.00	0.03	0.01	0.01
0.12	0.101	0.01	0.08	0.00	0.03	0.02	0.02
0.125	0.105	0.01	0.09	0.00	0.04	0.02	0.02
0.13	0.109	0.01	0.11	0.00	0.04	0.02	0.02
0.135	0.113	0.02	0.12	0.00	0.05	0.03	0.03
0.14	0.117	0.02	0.14	0.00	0.05	0.03	0.03
0.145	0.122	0.02	0.16	0.00	0.06	0.04	0.04
0.15	0.126	0.02	0.17	0.00	0.07	0.04	0.04
0.155	0.130	0.03	0.19	0.00	0.07	0.05	0.05
0.16	0.134	0.03	0.21	0.01	0.08	0.06	0.06
0.165	0.138	0.03	0.23	0.01	0.09	0.06	0.06
0.17	0.143	0.04	0.25	0.01	0.09	0.07	0.07
0.175	0.147	0.04	0.27	0.01	0.10	0.08	0.08
0.18	0.151	0.05	0.29	0.02	0.11	0.09	0.09
0.185	0.155	0.05	0.32	0.02	0.12	0.10	0.10
0.19	0.159	0.06	0.34	0.02	0.13	0.11	0.12
0.195	0.163	0.06	0.36	0.03	0.14	0.12	0.13
0.2	0.168	0.07	0.38	0.03	0.14	0.13	0.14
0.205	0.172	0.07	0.40	0.04	0.15	0.15	0.16
0.21	0.176	0.08	0.43	0.05	0.16	0.16	0.17
0.215	0.180	0.08	0.45	0.06	0.17	0.17	0.19

Table B.2 Continued

Magnitude		7	Constant values from Holzer, et al. (2011)				
MSF		1.19274888					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.22	0.184	0.09	0.47	0.07	0.18	0.19	0.20
0.225	0.189	0.10	0.49	0.08	0.19	0.20	0.22
0.23	0.193	0.11	0.51	0.10	0.20	0.21	0.23
0.235	0.197	0.11	0.53	0.12	0.21	0.23	0.25
0.24	0.201	0.12	0.55	0.13	0.22	0.24	0.27
0.245	0.205	0.13	0.57	0.15	0.23	0.26	0.28
0.25	0.210	0.14	0.58	0.18	0.24	0.27	0.30
0.255	0.214	0.14	0.60	0.20	0.25	0.29	0.32
0.26	0.218	0.15	0.62	0.23	0.26	0.30	0.34
0.265	0.222	0.16	0.63	0.25	0.26	0.32	0.35
0.27	0.226	0.17	0.65	0.28	0.27	0.33	0.37
0.275	0.231	0.18	0.66	0.31	0.28	0.35	0.39
0.28	0.235	0.19	0.68	0.35	0.29	0.36	0.40
0.285	0.239	0.20	0.69	0.38	0.30	0.38	0.42
0.29	0.243	0.21	0.70	0.41	0.31	0.39	0.44
0.295	0.247	0.21	0.71	0.44	0.32	0.41	0.45
0.3	0.252	0.22	0.73	0.48	0.32	0.42	0.47
0.305	0.256	0.23	0.74	0.51	0.33	0.43	0.48
0.31	0.260	0.24	0.75	0.54	0.34	0.45	0.49
0.315	0.264	0.25	0.76	0.57	0.35	0.46	0.51
0.32	0.268	0.26	0.77	0.60	0.36	0.47	0.52
0.325	0.272	0.27	0.78	0.63	0.36	0.48	0.53
0.33	0.277	0.28	0.78	0.66	0.37	0.50	0.55
0.335	0.281	0.29	0.79	0.68	0.38	0.51	0.56
0.34	0.285	0.30	0.80	0.71	0.38	0.52	0.57
0.345	0.289	0.31	0.81	0.73	0.39	0.53	0.58
0.35	0.293	0.32	0.81	0.75	0.40	0.54	0.59
0.355	0.298	0.32	0.82	0.77	0.40	0.55	0.60
0.36	0.302	0.33	0.83	0.79	0.41	0.56	0.61
0.365	0.306	0.34	0.83	0.80	0.41	0.56	0.62
0.37	0.310	0.35	0.84	0.82	0.42	0.57	0.62
0.375	0.314	0.36	0.84	0.83	0.43	0.58	0.63
0.38	0.319	0.37	0.85	0.84	0.43	0.59	0.64
0.385	0.323	0.37	0.85	0.86	0.44	0.60	0.65
0.39	0.327	0.38	0.86	0.87	0.44	0.60	0.65
0.395	0.331	0.39	0.86	0.88	0.45	0.61	0.66
0.4	0.335	0.40	0.86	0.88	0.45	0.62	0.66
0.405	0.340	0.40	0.87	0.89	0.45	0.62	0.67
0.41	0.344	0.41	0.87	0.90	0.46	0.63	0.68
0.415	0.348	0.42	0.88	0.91	0.46	0.63	0.68
0.42	0.352	0.42	0.88	0.91	0.47	0.64	0.69
0.425	0.356	0.43	0.88	0.92	0.47	0.64	0.69
0.43	0.361	0.44	0.88	0.92	0.47	0.65	0.69

Table B.2 Continued

Magnitude		7	Constant values from Holzer, et al. (2011)				
MSF		1.19274888					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.435	0.365	0.44	0.89	0.93	0.48	0.65	0.70
0.44	0.369	0.45	0.89	0.93	0.48	0.66	0.70
0.445	0.373	0.46	0.89	0.93	0.49	0.66	0.71
0.45	0.377	0.46	0.89	0.94	0.49	0.66	0.71
0.455	0.381	0.47	0.90	0.94	0.49	0.67	0.71
0.46	0.386	0.47	0.90	0.94	0.50	0.67	0.72
0.465	0.390	0.48	0.90	0.95	0.50	0.68	0.72
0.47	0.394	0.48	0.90	0.95	0.50	0.68	0.72
0.475	0.398	0.49	0.91	0.95	0.50	0.68	0.72
0.48	0.402	0.49	0.91	0.95	0.51	0.68	0.73
0.485	0.407	0.50	0.91	0.95	0.51	0.69	0.73
0.49	0.411	0.50	0.91	0.96	0.51	0.69	0.73
0.495	0.415	0.51	0.91	0.96	0.51	0.69	0.73
0.5	0.419	0.51	0.91	0.96	0.52	0.69	0.74
0.505	0.423	0.51	0.92	0.96	0.52	0.70	0.74
0.51	0.428	0.52	0.92	0.96	0.52	0.70	0.74
0.515	0.432	0.52	0.92	0.96	0.52	0.70	0.74
0.52	0.436	0.53	0.92	0.96	0.53	0.70	0.74
0.525	0.440	0.53	0.92	0.96	0.53	0.71	0.75
0.53	0.444	0.53	0.92	0.97	0.53	0.71	0.75
0.535	0.449	0.54	0.92	0.97	0.53	0.71	0.75
0.54	0.453	0.54	0.92	0.97	0.53	0.71	0.75
0.545	0.457	0.54	0.92	0.97	0.54	0.71	0.75
0.55	0.461	0.55	0.93	0.97	0.54	0.71	0.75
0.555	0.465	0.55	0.93	0.97	0.54	0.72	0.75
0.56	0.470	0.55	0.93	0.97	0.54	0.72	0.75
0.565	0.474	0.55	0.93	0.97	0.54	0.72	0.76
0.57	0.478	0.56	0.93	0.97	0.54	0.72	0.76
0.575	0.482	0.56	0.93	0.97	0.54	0.72	0.76
0.58	0.486	0.56	0.93	0.97	0.55	0.72	0.76
0.585	0.490	0.56	0.93	0.97	0.55	0.72	0.76
0.59	0.495	0.57	0.93	0.97	0.55	0.72	0.76
0.595	0.499	0.57	0.93	0.97	0.55	0.73	0.76
0.6	0.503	0.57	0.93	0.97	0.55	0.73	0.76
0.605	0.507	0.57	0.93	0.97	0.55	0.73	0.76
0.61	0.511	0.58	0.93	0.97	0.55	0.73	0.76
0.615	0.516	0.58	0.94	0.97	0.56	0.73	0.76
0.62	0.520	0.58	0.94	0.97	0.56	0.73	0.77
0.625	0.524	0.58	0.94	0.97	0.56	0.73	0.77
0.63	0.528	0.58	0.94	0.97	0.56	0.73	0.77
0.635	0.532	0.58	0.94	0.97	0.56	0.73	0.77
0.64	0.537	0.59	0.94	0.97	0.56	0.73	0.77
0.645	0.541	0.59	0.94	0.97	0.56	0.73	0.77

Table B.2 Continued

Magnitude		7	Constant values from Holzer, et al. (2011)				
MSF		1.19274888					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	**PGA/MSF**	**Alluvial Fan**	**Beach Ridge**	**Delta**	**Floodplain**	**Lagoonal**	**Fill**
0.65	0.545	0.59	0.94	0.97	0.56	0.73	0.77
0.655	0.549	0.59	0.94	0.97	0.56	0.73	0.77
0.66	0.553	0.59	0.94	0.97	0.56	0.74	0.77
0.665	0.558	0.59	0.94	0.97	0.56	0.74	0.77
0.67	0.562	0.60	0.94	0.97	0.57	0.74	0.77
0.675	0.566	0.60	0.94	0.97	0.57	0.74	0.77
0.68	0.570	0.60	0.94	0.97	0.57	0.74	0.77
0.685	0.574	0.60	0.94	0.97	0.57	0.74	0.77
0.69	0.578	0.60	0.94	0.97	0.57	0.74	0.77
0.695	0.583	0.60	0.94	0.97	0.57	0.74	0.77
0.7	0.587	0.60	0.94	0.97	0.57	0.74	0.77
0.705	0.591	0.60	0.94	0.97	0.57	0.74	0.77
0.71	0.595	0.61	0.94	0.97	0.57	0.74	0.77
0.715	0.599	0.61	0.94	0.97	0.57	0.74	0.77
0.72	0.604	0.61	0.94	0.98	0.57	0.74	0.77
0.725	0.608	0.61	0.94	0.98	0.57	0.74	0.77
0.73	0.612	0.61	0.94	0.98	0.57	0.74	0.77
0.735	0.616	0.61	0.94	0.98	0.57	0.74	0.77
0.74	0.620	0.61	0.94	0.98	0.58	0.74	0.77
0.745	0.625	0.61	0.95	0.98	0.58	0.74	0.78
0.75	0.629	0.61	0.95	0.98	0.58	0.74	0.78
0.755	0.633	0.61	0.95	0.98	0.58	0.74	0.78
0.76	0.637	0.62	0.95	0.98	0.58	0.74	0.78
0.765	0.641	0.62	0.95	0.98	0.58	0.74	0.78
0.77	0.646	0.62	0.95	0.98	0.58	0.74	0.78
0.775	0.650	0.62	0.95	0.98	0.58	0.74	0.78
0.78	0.654	0.62	0.95	0.98	0.58	0.74	0.78
0.785	0.658	0.62	0.95	0.98	0.58	0.75	0.78
0.79	0.662	0.62	0.95	0.98	0.58	0.75	0.78
0.795	0.667	0.62	0.95	0.98	0.58	0.75	0.78
0.8	0.671	0.62	0.95	0.98	0.58	0.75	0.78
0.805	0.675	0.62	0.95	0.98	0.58	0.75	0.78
0.81	0.679	0.62	0.95	0.98	0.58	0.75	0.78
0.815	0.683	0.62	0.95	0.98	0.58	0.75	0.78
0.82	0.687	0.62	0.95	0.98	0.58	0.75	0.78
0.825	0.692	0.62	0.95	0.98	0.58	0.75	0.78
0.83	0.696	0.62	0.95	0.98	0.58	0.75	0.78
0.835	0.700	0.63	0.95	0.98	0.58	0.75	0.78
0.84	0.704	0.63	0.95	0.98	0.58	0.75	0.78
0.845	0.708	0.63	0.95	0.98	0.58	0.75	0.78
0.85	0.713	0.63	0.95	0.98	0.58	0.75	0.78
0.855	0.717	0.63	0.95	0.98	0.58	0.75	0.78
0.86	0.721	0.63	0.95	0.98	0.59	0.75	0.78

Table B.2 Continued

Magnitude		7	Constant values from Holzer, et al. (2011)					
MSF		1.19274888						
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.865	0.725	0.63	0.95	0.98	0.59	0.75	0.78
0.87	0.729	0.63	0.95	0.98	0.59	0.75	0.78
0.875	0.734	0.63	0.95	0.98	0.59	0.75	0.78
0.88	0.738	0.63	0.95	0.98	0.59	0.75	0.78
0.885	0.742	0.63	0.95	0.98	0.59	0.75	0.78
0.89	0.746	0.63	0.95	0.98	0.59	0.75	0.78
0.895	0.750	0.63	0.95	0.98	0.59	0.75	0.78
0.9	0.755	0.63	0.95	0.98	0.59	0.75	0.78
0.905	0.759	0.63	0.95	0.98	0.59	0.75	0.78
0.91	0.763	0.63	0.95	0.98	0.59	0.75	0.78
0.915	0.767	0.63	0.95	0.98	0.59	0.75	0.78
0.92	0.771	0.63	0.95	0.98	0.59	0.75	0.78
0.925	0.776	0.63	0.95	0.98	0.59	0.75	0.78
0.93	0.780	0.63	0.95	0.98	0.59	0.75	0.78
0.935	0.784	0.63	0.95	0.98	0.59	0.75	0.78
0.94	0.788	0.63	0.95	0.98	0.59	0.75	0.78
0.945	0.792	0.63	0.95	0.98	0.59	0.75	0.78
0.95	0.796	0.63	0.95	0.98	0.59	0.75	0.78
0.955	0.801	0.64	0.95	0.98	0.59	0.75	0.78
0.96	0.805	0.64	0.95	0.98	0.59	0.75	0.78
0.965	0.809	0.64	0.95	0.98	0.59	0.75	0.78
0.97	0.813	0.64	0.95	0.98	0.59	0.75	0.78
0.975	0.817	0.64	0.95	0.98	0.59	0.75	0.78
0.98	0.822	0.64	0.95	0.98	0.59	0.75	0.78
0.985	0.826	0.64	0.95	0.98	0.59	0.75	0.78
0.99	0.830	0.64	0.95	0.98	0.59	0.75	0.78
0.995	0.834	0.64	0.95	0.98	0.59	0.75	0.78
1	0.838	0.64	0.95	0.98	0.59	0.75	0.78

Table B.3 - Probability values M=6.5

Magnitude		6.5	Constant values from Holzer, et al. (2011)				
MSF		1.441922129					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.005	0.003	0.00	0.00	0.00	0.00	0.00	0.00
0.01	0.007	0.00	0.00	0.00	0.00	0.00	0.00
0.015	0.010	0.00	0.00	0.00	0.00	0.00	0.00
0.02	0.014	0.00	0.00	0.00	0.00	0.00	0.00
0.025	0.017	0.00	0.00	0.00	0.00	0.00	0.00
0.03	0.021	0.00	0.00	0.00	0.00	0.00	0.00
0.035	0.024	0.00	0.00	0.00	0.00	0.00	0.00
0.04	0.028	0.00	0.00	0.00	0.00	0.00	0.00
0.045	0.031	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.035	0.00	0.00	0.00	0.00	0.00	0.00
0.055	0.038	0.00	0.00	0.00	0.00	0.00	0.00
0.06	0.042	0.00	0.00	0.00	0.00	0.00	0.00
0.065	0.045	0.00	0.00	0.00	0.00	0.00	0.00
0.07	0.049	0.00	0.01	0.00	0.00	0.00	0.00
0.075	0.052	0.00	0.01	0.00	0.00	0.00	0.00
0.08	0.055	0.00	0.01	0.00	0.01	0.00	0.00
0.085	0.059	0.00	0.01	0.00	0.01	0.00	0.00
0.09	0.062	0.00	0.01	0.00	0.01	0.00	0.00
0.095	0.066	0.00	0.02	0.00	0.01	0.00	0.00
0.1	0.069	0.00	0.02	0.00	0.01	0.00	0.00
0.105	0.073	0.00	0.03	0.00	0.01	0.00	0.00
0.11	0.076	0.00	0.03	0.00	0.01	0.01	0.00
0.115	0.080	0.00	0.04	0.00	0.02	0.01	0.01
0.12	0.083	0.01	0.04	0.00	0.02	0.01	0.01
0.125	0.087	0.01	0.05	0.00	0.02	0.01	0.01
0.13	0.090	0.01	0.06	0.00	0.02	0.01	0.01
0.135	0.094	0.01	0.06	0.00	0.03	0.01	0.01
0.14	0.097	0.01	0.07	0.00	0.03	0.01	0.01
0.145	0.101	0.01	0.08	0.00	0.03	0.02	0.02
0.15	0.104	0.01	0.09	0.00	0.04	0.02	0.02
0.155	0.107	0.01	0.10	0.00	0.04	0.02	0.02
0.16	0.111	0.02	0.12	0.00	0.05	0.03	0.02
0.165	0.114	0.02	0.13	0.00	0.05	0.03	0.03
0.17	0.118	0.02	0.14	0.00	0.06	0.03	0.03
0.175	0.121	0.02	0.15	0.00	0.06	0.04	0.04
0.18	0.125	0.02	0.17	0.00	0.07	0.04	0.04
0.185	0.128	0.03	0.18	0.00	0.07	0.05	0.05
0.19	0.132	0.03	0.20	0.01	0.08	0.05	0.05
0.195	0.135	0.03	0.22	0.01	0.08	0.06	0.06
0.2	0.139	0.03	0.23	0.01	0.09	0.06	0.07
0.205	0.142	0.04	0.25	0.01	0.09	0.07	0.07
0.21	0.146	0.04	0.27	0.01	0.10	0.08	0.08
0.215	0.149	0.04	0.29	0.01	0.11	0.09	0.09

Table B.3 Continued

Magnitude		6.5	Constant values from Holzer, et al. (2011)				
MSF		1.441922129					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.22	0.153	0.05	0.30	0.02	0.11	0.09	0.10
0.225	0.156	0.05	0.32	0.02	0.12	0.10	0.11
0.23	0.160	0.06	0.34	0.02	0.13	0.11	0.12
0.235	0.163	0.06	0.36	0.03	0.13	0.12	0.13
0.24	0.166	0.06	0.38	0.03	0.14	0.13	0.14
0.245	0.170	0.07	0.39	0.04	0.15	0.14	0.15
0.25	0.173	0.07	0.41	0.04	0.16	0.15	0.16
0.255	0.177	0.08	0.43	0.05	0.16	0.16	0.17
0.26	0.180	0.08	0.45	0.06	0.17	0.17	0.19
0.265	0.184	0.09	0.47	0.07	0.18	0.18	0.20
0.27	0.187	0.10	0.48	0.08	0.19	0.20	0.21
0.275	0.191	0.10	0.50	0.09	0.19	0.21	0.23
0.28	0.194	0.11	0.52	0.10	0.20	0.22	0.24
0.285	0.198	0.11	0.53	0.12	0.21	0.23	0.25
0.29	0.201	0.12	0.55	0.13	0.22	0.24	0.27
0.295	0.205	0.13	0.56	0.15	0.23	0.26	0.28
0.3	0.208	0.13	0.58	0.17	0.23	0.27	0.30
0.305	0.212	0.14	0.59	0.19	0.24	0.28	0.31
0.31	0.215	0.15	0.61	0.21	0.25	0.29	0.32
0.315	0.218	0.15	0.62	0.23	0.26	0.31	0.34
0.32	0.222	0.16	0.63	0.25	0.26	0.32	0.35
0.325	0.225	0.17	0.65	0.28	0.27	0.33	0.37
0.33	0.229	0.18	0.66	0.30	0.28	0.34	0.38
0.335	0.232	0.18	0.67	0.33	0.29	0.36	0.39
0.34	0.236	0.19	0.68	0.35	0.29	0.37	0.41
0.345	0.239	0.20	0.69	0.38	0.30	0.38	0.42
0.35	0.243	0.20	0.70	0.41	0.31	0.39	0.43
0.355	0.246	0.21	0.71	0.43	0.31	0.40	0.45
0.36	0.250	0.22	0.72	0.46	0.32	0.42	0.46
0.365	0.253	0.23	0.73	0.49	0.33	0.43	0.47
0.37	0.257	0.24	0.74	0.52	0.33	0.44	0.48
0.375	0.260	0.24	0.75	0.54	0.34	0.45	0.49
0.38	0.264	0.25	0.76	0.57	0.35	0.46	0.51
0.385	0.267	0.26	0.76	0.59	0.35	0.47	0.52
0.39	0.270	0.27	0.77	0.62	0.36	0.48	0.53
0.395	0.274	0.27	0.78	0.64	0.36	0.49	0.54
0.4	0.277	0.28	0.78	0.66	0.37	0.50	0.55
0.405	0.281	0.29	0.79	0.68	0.38	0.51	0.56
0.41	0.284	0.30	0.80	0.70	0.38	0.52	0.57
0.415	0.288	0.30	0.80	0.72	0.39	0.52	0.57
0.42	0.291	0.31	0.81	0.74	0.39	0.53	0.58
0.425	0.295	0.32	0.81	0.75	0.40	0.54	0.59
0.43	0.298	0.33	0.82	0.77	0.40	0.55	0.60

Table B.3 Continued

Magnitude		6.5	Constant values from Holzer, et al. (2011)				
MSF		1.441922129					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.435	0.302	0.33	0.83	0.79	0.41	0.56	0.61
0.44	0.305	0.34	0.83	0.80	0.41	0.56	0.61
0.445	0.309	0.35	0.83	0.81	0.42	0.57	0.62
0.45	0.312	0.35	0.84	0.82	0.42	0.58	0.63
0.455	0.316	0.36	0.84	0.83	0.43	0.58	0.63
0.46	0.319	0.37	0.85	0.85	0.43	0.59	0.64
0.465	0.322	0.37	0.85	0.85	0.44	0.60	0.65
0.47	0.326	0.38	0.85	0.86	0.44	0.60	0.65
0.475	0.329	0.39	0.86	0.87	0.44	0.61	0.66
0.48	0.333	0.39	0.86	0.88	0.45	0.61	0.66
0.485	0.336	0.40	0.87	0.89	0.45	0.62	0.67
0.49	0.340	0.40	0.87	0.89	0.45	0.62	0.67
0.495	0.343	0.41	0.87	0.90	0.46	0.63	0.68
0.5	0.347	0.42	0.87	0.90	0.46	0.63	0.68
0.505	0.350	0.42	0.88	0.91	0.47	0.64	0.68
0.51	0.354	0.43	0.88	0.91	0.47	0.64	0.69
0.515	0.357	0.43	0.88	0.92	0.47	0.64	0.69
0.52	0.361	0.44	0.88	0.92	0.48	0.65	0.69
0.525	0.364	0.44	0.89	0.93	0.48	0.65	0.70
0.53	0.368	0.45	0.89	0.93	0.48	0.66	0.70
0.535	0.371	0.45	0.89	0.93	0.48	0.66	0.70
0.54	0.375	0.46	0.89	0.94	0.49	0.66	0.71
0.545	0.378	0.46	0.90	0.94	0.49	0.67	0.71
0.55	0.381	0.47	0.90	0.94	0.49	0.67	0.71
0.555	0.385	0.47	0.90	0.94	0.49	0.67	0.72
0.56	0.388	0.48	0.90	0.95	0.50	0.67	0.72
0.565	0.392	0.48	0.90	0.95	0.50	0.68	0.72
0.57	0.395	0.48	0.90	0.95	0.50	0.68	0.72
0.575	0.399	0.49	0.91	0.95	0.50	0.68	0.73
0.58	0.402	0.49	0.91	0.95	0.51	0.68	0.73
0.585	0.406	0.50	0.91	0.95	0.51	0.69	0.73
0.59	0.409	0.50	0.91	0.96	0.51	0.69	0.73
0.595	0.413	0.50	0.91	0.96	0.51	0.69	0.73
0.6	0.416	0.51	0.91	0.96	0.52	0.69	0.73
0.605	0.420	0.51	0.91	0.96	0.52	0.70	0.74
0.61	0.423	0.51	0.92	0.96	0.52	0.70	0.74
0.615	0.427	0.52	0.92	0.96	0.52	0.70	0.74
0.62	0.430	0.52	0.92	0.96	0.52	0.70	0.74
0.625	0.433	0.52	0.92	0.96	0.52	0.70	0.74
0.63	0.437	0.53	0.92	0.96	0.53	0.70	0.74
0.635	0.440	0.53	0.92	0.96	0.53	0.71	0.75
0.64	0.444	0.53	0.92	0.97	0.53	0.71	0.75
0.645	0.447	0.53	0.92	0.97	0.53	0.71	0.75

Table B.3 Continued

Magnitude		6.5	Constant values from Holzer, et al. (2011)				
MSF		1.441922129					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.65	0.451	0.54	0.92	0.97	0.53	0.71	0.75
0.655	0.454	0.54	0.92	0.97	0.53	0.71	0.75
0.66	0.458	0.54	0.93	0.97	0.54	0.71	0.75
0.665	0.461	0.55	0.93	0.97	0.54	0.71	0.75
0.67	0.465	0.55	0.93	0.97	0.54	0.72	0.75
0.675	0.468	0.55	0.93	0.97	0.54	0.72	0.75
0.68	0.472	0.55	0.93	0.97	0.54	0.72	0.76
0.685	0.475	0.55	0.93	0.97	0.54	0.72	0.76
0.69	0.479	0.56	0.93	0.97	0.54	0.72	0.76
0.695	0.482	0.56	0.93	0.97	0.54	0.72	0.76
0.7	0.485	0.56	0.93	0.97	0.55	0.72	0.76
0.705	0.489	0.56	0.93	0.97	0.55	0.72	0.76
0.71	0.492	0.57	0.93	0.97	0.55	0.72	0.76
0.715	0.496	0.57	0.93	0.97	0.55	0.72	0.76
0.72	0.499	0.57	0.93	0.97	0.55	0.73	0.76
0.725	0.503	0.57	0.93	0.97	0.55	0.73	0.76
0.73	0.506	0.57	0.93	0.97	0.55	0.73	0.76
0.735	0.510	0.57	0.93	0.97	0.55	0.73	0.76
0.74	0.513	0.58	0.94	0.97	0.55	0.73	0.76
0.745	0.517	0.58	0.94	0.97	0.56	0.73	0.76
0.75	0.520	0.58	0.94	0.97	0.56	0.73	0.77
0.755	0.524	0.58	0.94	0.97	0.56	0.73	0.77
0.76	0.527	0.58	0.94	0.97	0.56	0.73	0.77
0.765	0.531	0.58	0.94	0.97	0.56	0.73	0.77
0.77	0.534	0.59	0.94	0.97	0.56	0.73	0.77
0.775	0.537	0.59	0.94	0.97	0.56	0.73	0.77
0.78	0.541	0.59	0.94	0.97	0.56	0.73	0.77
0.785	0.544	0.59	0.94	0.97	0.56	0.73	0.77
0.79	0.548	0.59	0.94	0.97	0.56	0.73	0.77
0.795	0.551	0.59	0.94	0.97	0.56	0.74	0.77
0.8	0.555	0.59	0.94	0.97	0.56	0.74	0.77
0.805	0.558	0.59	0.94	0.97	0.57	0.74	0.77
0.81	0.562	0.60	0.94	0.97	0.57	0.74	0.77
0.815	0.565	0.60	0.94	0.97	0.57	0.74	0.77
0.82	0.569	0.60	0.94	0.97	0.57	0.74	0.77
0.825	0.572	0.60	0.94	0.97	0.57	0.74	0.77
0.83	0.576	0.60	0.94	0.97	0.57	0.74	0.77
0.835	0.579	0.60	0.94	0.97	0.57	0.74	0.77
0.84	0.583	0.60	0.94	0.97	0.57	0.74	0.77
0.845	0.586	0.60	0.94	0.97	0.57	0.74	0.77
0.85	0.589	0.60	0.94	0.97	0.57	0.74	0.77
0.855	0.593	0.61	0.94	0.97	0.57	0.74	0.77
0.86	0.596	0.61	0.94	0.97	0.57	0.74	0.77

Table B.3 Continued

Magnitude		6.5	Constant values from Holzer, et al. (2011)				
MSF		1.441922129					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.865	0.600	0.61	0.94	0.97	0.57	0.74	0.77
0.87	0.603	0.61	0.94	0.98	0.57	0.74	0.77
0.875	0.607	0.61	0.94	0.98	0.57	0.74	0.77
0.88	0.610	0.61	0.94	0.98	0.57	0.74	0.77
0.885	0.614	0.61	0.94	0.98	0.57	0.74	0.77
0.89	0.617	0.61	0.94	0.98	0.57	0.74	0.77
0.895	0.621	0.61	0.94	0.98	0.58	0.74	0.77
0.9	0.624	0.61	0.95	0.98	0.58	0.74	0.78
0.905	0.628	0.61	0.95	0.98	0.58	0.74	0.78
0.91	0.631	0.61	0.95	0.98	0.58	0.74	0.78
0.915	0.635	0.61	0.95	0.98	0.58	0.74	0.78
0.92	0.638	0.62	0.95	0.98	0.58	0.74	0.78
0.925	0.642	0.62	0.95	0.98	0.58	0.74	0.78
0.93	0.645	0.62	0.95	0.98	0.58	0.74	0.78
0.935	0.648	0.62	0.95	0.98	0.58	0.74	0.78
0.94	0.652	0.62	0.95	0.98	0.58	0.74	0.78
0.945	0.655	0.62	0.95	0.98	0.58	0.74	0.78
0.95	0.659	0.62	0.95	0.98	0.58	0.75	0.78
0.955	0.662	0.62	0.95	0.98	0.58	0.75	0.78
0.96	0.666	0.62	0.95	0.98	0.58	0.75	0.78
0.965	0.669	0.62	0.95	0.98	0.58	0.75	0.78
0.97	0.673	0.62	0.95	0.98	0.58	0.75	0.78
0.975	0.676	0.62	0.95	0.98	0.58	0.75	0.78
0.98	0.680	0.62	0.95	0.98	0.58	0.75	0.78
0.985	0.683	0.62	0.95	0.98	0.58	0.75	0.78
0.99	0.687	0.62	0.95	0.98	0.58	0.75	0.78
0.995	0.690	0.62	0.95	0.98	0.58	0.75	0.78
1	0.694	0.62	0.95	0.98	0.58	0.75	0.78

Table B.4 - Probability values M=6.0

Magnitude		6	Constant values from Holzer, et al. (2011)				
MSF		1.76983508					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.005	0.003	0.00	0.00	0.00	0.00	0.00	0.00
0.01	0.006	0.00	0.00	0.00	0.00	0.00	0.00
0.015	0.008	0.00	0.00	0.00	0.00	0.00	0.00
0.02	0.011	0.00	0.00	0.00	0.00	0.00	0.00
0.025	0.014	0.00	0.00	0.00	0.00	0.00	0.00
0.03	0.017	0.00	0.00	0.00	0.00	0.00	0.00
0.035	0.020	0.00	0.00	0.00	0.00	0.00	0.00
0.04	0.023	0.00	0.00	0.00	0.00	0.00	0.00
0.045	0.025	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.028	0.00	0.00	0.00	0.00	0.00	0.00
0.055	0.031	0.00	0.00	0.00	0.00	0.00	0.00
0.06	0.034	0.00	0.00	0.00	0.00	0.00	0.00
0.065	0.037	0.00	0.00	0.00	0.00	0.00	0.00
0.07	0.040	0.00	0.00	0.00	0.00	0.00	0.00
0.075	0.042	0.00	0.00	0.00	0.00	0.00	0.00
0.08	0.045	0.00	0.00	0.00	0.00	0.00	0.00
0.085	0.048	0.00	0.01	0.00	0.00	0.00	0.00
0.09	0.051	0.00	0.01	0.00	0.00	0.00	0.00
0.095	0.054	0.00	0.01	0.00	0.00	0.00	0.00
0.1	0.057	0.00	0.01	0.00	0.01	0.00	0.00
0.105	0.059	0.00	0.01	0.00	0.01	0.00	0.00
0.11	0.062	0.00	0.01	0.00	0.01	0.00	0.00
0.115	0.065	0.00	0.02	0.00	0.01	0.00	0.00
0.12	0.068	0.00	0.02	0.00	0.01	0.00	0.00
0.125	0.071	0.00	0.02	0.00	0.01	0.00	0.00
0.13	0.073	0.00	0.03	0.00	0.01	0.00	0.00
0.135	0.076	0.00	0.03	0.00	0.01	0.01	0.00
0.14	0.079	0.00	0.03	0.00	0.02	0.01	0.01
0.145	0.082	0.00	0.04	0.00	0.02	0.01	0.01
0.15	0.085	0.01	0.04	0.00	0.02	0.01	0.01
0.155	0.088	0.01	0.05	0.00	0.02	0.01	0.01
0.16	0.090	0.01	0.06	0.00	0.02	0.01	0.01
0.165	0.093	0.01	0.06	0.00	0.03	0.01	0.01
0.17	0.096	0.01	0.07	0.00	0.03	0.01	0.01
0.175	0.099	0.01	0.08	0.00	0.03	0.02	0.01
0.18	0.102	0.01	0.09	0.00	0.04	0.02	0.02
0.185	0.105	0.01	0.09	0.00	0.04	0.02	0.02
0.19	0.107	0.01	0.10	0.00	0.04	0.02	0.02
0.195	0.110	0.01	0.11	0.00	0.05	0.03	0.02
0.2	0.113	0.02	0.12	0.00	0.05	0.03	0.03
0.205	0.116	0.02	0.13	0.00	0.05	0.03	0.03
0.21	0.119	0.02	0.14	0.00	0.06	0.03	0.03
0.215	0.121	0.02	0.16	0.00	0.06	0.04	0.04

Table B.4 Continued

Magnitude		6	Constant values from Holzer, et al. (2011)				
MSF		1.76983508					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.22	0.124	0.02	0.17	0.00	0.06	0.04	0.04
0.225	0.127	0.02	0.18	0.00	0.07	0.05	0.05
0.23	0.130	0.03	0.19	0.00	0.07	0.05	0.05
0.235	0.133	0.03	0.20	0.01	0.08	0.05	0.05
0.24	0.136	0.03	0.22	0.01	0.08	0.06	0.06
0.245	0.138	0.03	0.23	0.01	0.09	0.06	0.07
0.25	0.141	0.04	0.25	0.01	0.09	0.07	0.07
0.255	0.144	0.04	0.26	0.01	0.10	0.08	0.08
0.26	0.147	0.04	0.27	0.01	0.10	0.08	0.08
0.265	0.150	0.04	0.29	0.01	0.11	0.09	0.09
0.27	0.153	0.05	0.30	0.02	0.11	0.09	0.10
0.275	0.155	0.05	0.32	0.02	0.12	0.10	0.11
0.28	0.158	0.05	0.33	0.02	0.12	0.11	0.11
0.285	0.161	0.06	0.35	0.03	0.13	0.12	0.12
0.29	0.164	0.06	0.36	0.03	0.14	0.12	0.13
0.295	0.167	0.07	0.38	0.03	0.14	0.13	0.14
0.3	0.170	0.07	0.39	0.04	0.15	0.14	0.15
0.305	0.172	0.07	0.41	0.04	0.15	0.15	0.16
0.31	0.175	0.08	0.42	0.05	0.16	0.16	0.17
0.315	0.178	0.08	0.44	0.05	0.17	0.16	0.18
0.32	0.181	0.09	0.45	0.06	0.17	0.17	0.19
0.325	0.184	0.09	0.46	0.07	0.18	0.18	0.20
0.33	0.186	0.09	0.48	0.08	0.19	0.19	0.21
0.335	0.189	0.10	0.49	0.09	0.19	0.20	0.22
0.34	0.192	0.10	0.51	0.10	0.20	0.21	0.23
0.345	0.195	0.11	0.52	0.11	0.20	0.22	0.24
0.35	0.198	0.11	0.53	0.12	0.21	0.23	0.25
0.355	0.201	0.12	0.55	0.13	0.22	0.24	0.27
0.36	0.203	0.12	0.56	0.14	0.22	0.25	0.28
0.365	0.206	0.13	0.57	0.16	0.23	0.26	0.29
0.37	0.209	0.13	0.58	0.17	0.24	0.27	0.30
0.375	0.212	0.14	0.59	0.19	0.24	0.28	0.31
0.38	0.215	0.15	0.60	0.21	0.25	0.29	0.32
0.385	0.218	0.15	0.62	0.22	0.25	0.30	0.33
0.39	0.220	0.16	0.63	0.24	0.26	0.31	0.35
0.395	0.223	0.16	0.64	0.26	0.27	0.32	0.36
0.4	0.226	0.17	0.65	0.28	0.27	0.33	0.37
0.405	0.229	0.17	0.66	0.30	0.28	0.34	0.38
0.41	0.232	0.18	0.67	0.32	0.28	0.35	0.39
0.415	0.234	0.19	0.68	0.34	0.29	0.36	0.40
0.42	0.237	0.19	0.68	0.37	0.30	0.37	0.41
0.425	0.240	0.20	0.69	0.39	0.30	0.38	0.42
0.43	0.243	0.21	0.70	0.41	0.31	0.39	0.44

Table B.4 Continued

Magnitude		6	Constant values from Holzer, et al. (2011)				
MSF		1.76983508					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.435	0.246	0.21	0.71	0.43	0.31	0.40	0.45
0.44	0.249	0.22	0.72	0.45	0.32	0.41	0.46
0.445	0.251	0.22	0.73	0.48	0.32	0.42	0.47
0.45	0.254	0.23	0.73	0.50	0.33	0.43	0.48
0.455	0.257	0.24	0.74	0.52	0.33	0.44	0.49
0.46	0.260	0.24	0.75	0.54	0.34	0.45	0.49
0.465	0.263	0.25	0.75	0.56	0.35	0.46	0.50
0.47	0.266	0.26	0.76	0.58	0.35	0.46	0.51
0.475	0.268	0.26	0.77	0.60	0.36	0.47	0.52
0.48	0.271	0.27	0.77	0.62	0.36	0.48	0.53
0.485	0.274	0.27	0.78	0.64	0.37	0.49	0.54
0.49	0.277	0.28	0.78	0.66	0.37	0.50	0.55
0.495	0.280	0.29	0.79	0.67	0.37	0.50	0.55
0.5	0.283	0.29	0.79	0.69	0.38	0.51	0.56
0.505	0.285	0.30	0.80	0.71	0.38	0.52	0.57
0.51	0.288	0.30	0.80	0.72	0.39	0.52	0.58
0.515	0.291	0.31	0.81	0.74	0.39	0.53	0.58
0.52	0.294	0.32	0.81	0.75	0.40	0.54	0.59
0.525	0.297	0.32	0.82	0.76	0.40	0.54	0.60
0.53	0.299	0.33	0.82	0.78	0.40	0.55	0.60
0.535	0.302	0.33	0.83	0.79	0.41	0.56	0.61
0.54	0.305	0.34	0.83	0.80	0.41	0.56	0.61
0.545	0.308	0.35	0.83	0.81	0.42	0.57	0.62
0.55	0.311	0.35	0.84	0.82	0.42	0.57	0.62
0.555	0.314	0.36	0.84	0.83	0.42	0.58	0.63
0.56	0.316	0.36	0.84	0.84	0.43	0.58	0.63
0.565	0.319	0.37	0.85	0.85	0.43	0.59	0.64
0.57	0.322	0.37	0.85	0.85	0.43	0.59	0.64
0.575	0.325	0.38	0.85	0.86	0.44	0.60	0.65
0.58	0.328	0.38	0.86	0.87	0.44	0.60	0.65
0.585	0.331	0.39	0.86	0.87	0.44	0.61	0.66
0.59	0.333	0.39	0.86	0.88	0.45	0.61	0.66
0.595	0.336	0.40	0.87	0.89	0.45	0.62	0.67
0.6	0.339	0.40	0.87	0.89	0.45	0.62	0.67
0.605	0.342	0.41	0.87	0.90	0.46	0.62	0.67
0.61	0.345	0.41	0.87	0.90	0.46	0.63	0.68
0.615	0.347	0.42	0.87	0.91	0.46	0.63	0.68
0.62	0.350	0.42	0.88	0.91	0.47	0.64	0.68
0.625	0.353	0.43	0.88	0.91	0.47	0.64	0.69
0.63	0.356	0.43	0.88	0.92	0.47	0.64	0.69
0.635	0.359	0.43	0.88	0.92	0.47	0.65	0.69
0.64	0.362	0.44	0.89	0.92	0.48	0.65	0.70
0.645	0.364	0.44	0.89	0.93	0.48	0.65	0.70

Table B.4 Continued

Magnitude		6	Constant values from Holzer, et al. (2011)				
MSF		1.76983508					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.65	0.367	0.45	0.89	0.93	0.48	0.65	0.70
0.655	0.370	0.45	0.89	0.93	0.48	0.66	0.70
0.66	0.373	0.46	0.89	0.93	0.49	0.66	0.71
0.665	0.376	0.46	0.89	0.94	0.49	0.66	0.71
0.67	0.379	0.46	0.90	0.94	0.49	0.67	0.71
0.675	0.381	0.47	0.90	0.94	0.49	0.67	0.71
0.68	0.384	0.47	0.90	0.94	0.49	0.67	0.72
0.685	0.387	0.47	0.90	0.94	0.50	0.67	0.72
0.69	0.390	0.48	0.90	0.95	0.50	0.68	0.72
0.695	0.393	0.48	0.90	0.95	0.50	0.68	0.72
0.7	0.396	0.48	0.90	0.95	0.50	0.68	0.72
0.705	0.398	0.49	0.91	0.95	0.50	0.68	0.72
0.71	0.401	0.49	0.91	0.95	0.51	0.68	0.73
0.715	0.404	0.49	0.91	0.95	0.51	0.69	0.73
0.72	0.407	0.50	0.91	0.95	0.51	0.69	0.73
0.725	0.410	0.50	0.91	0.96	0.51	0.69	0.73
0.73	0.412	0.50	0.91	0.96	0.51	0.69	0.73
0.735	0.415	0.51	0.91	0.96	0.51	0.69	0.73
0.74	0.418	0.51	0.91	0.96	0.52	0.69	0.74
0.745	0.421	0.51	0.91	0.96	0.52	0.70	0.74
0.75	0.424	0.51	0.92	0.96	0.52	0.70	0.74
0.755	0.427	0.52	0.92	0.96	0.52	0.70	0.74
0.76	0.429	0.52	0.92	0.96	0.52	0.70	0.74
0.765	0.432	0.52	0.92	0.96	0.52	0.70	0.74
0.77	0.435	0.52	0.92	0.96	0.53	0.70	0.74
0.775	0.438	0.53	0.92	0.96	0.53	0.70	0.74
0.78	0.441	0.53	0.92	0.96	0.53	0.71	0.75
0.785	0.444	0.53	0.92	0.97	0.53	0.71	0.75
0.79	0.446	0.53	0.92	0.97	0.53	0.71	0.75
0.795	0.449	0.54	0.92	0.97	0.53	0.71	0.75
0.8	0.452	0.54	0.92	0.97	0.53	0.71	0.75
0.805	0.455	0.54	0.92	0.97	0.53	0.71	0.75
0.81	0.458	0.54	0.93	0.97	0.54	0.71	0.75
0.815	0.460	0.54	0.93	0.97	0.54	0.71	0.75
0.82	0.463	0.55	0.93	0.97	0.54	0.71	0.75
0.825	0.466	0.55	0.93	0.97	0.54	0.72	0.75
0.83	0.469	0.55	0.93	0.97	0.54	0.72	0.75
0.835	0.472	0.55	0.93	0.97	0.54	0.72	0.76
0.84	0.475	0.55	0.93	0.97	0.54	0.72	0.76
0.845	0.477	0.56	0.93	0.97	0.54	0.72	0.76
0.85	0.480	0.56	0.93	0.97	0.54	0.72	0.76
0.855	0.483	0.56	0.93	0.97	0.55	0.72	0.76
0.86	0.486	0.56	0.93	0.97	0.55	0.72	0.76

Table B.4 Continued

Magnitude		6	Constant values from Holzer, et al. (2011)				
MSF		1.76983508					
a		0.6503	0.9542	0.9759	0.6018	0.7539	0.7826
b		0.2981	0.1861	0.253	0.2397	0.2383	0.2315
c		-3.7789	-3.84212	-8.0436	-3.2337	-4.3654	-4.6645
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.865	0.489	0.56	0.93	0.97	0.55	0.72	0.76
0.87	0.492	0.56	0.93	0.97	0.55	0.72	0.76
0.875	0.494	0.57	0.93	0.97	0.55	0.72	0.76
0.88	0.497	0.57	0.93	0.97	0.55	0.72	0.76
0.885	0.500	0.57	0.93	0.97	0.55	0.73	0.76
0.89	0.503	0.57	0.93	0.97	0.55	0.73	0.76
0.895	0.506	0.57	0.93	0.97	0.55	0.73	0.76
0.9	0.509	0.57	0.93	0.97	0.55	0.73	0.76
0.905	0.511	0.58	0.93	0.97	0.55	0.73	0.76
0.91	0.514	0.58	0.94	0.97	0.55	0.73	0.76
0.915	0.517	0.58	0.94	0.97	0.56	0.73	0.76
0.92	0.520	0.58	0.94	0.97	0.56	0.73	0.77
0.925	0.523	0.58	0.94	0.97	0.56	0.73	0.77
0.93	0.525	0.58	0.94	0.97	0.56	0.73	0.77
0.935	0.528	0.58	0.94	0.97	0.56	0.73	0.77
0.94	0.531	0.58	0.94	0.97	0.56	0.73	0.77
0.945	0.534	0.59	0.94	0.97	0.56	0.73	0.77
0.95	0.537	0.59	0.94	0.97	0.56	0.73	0.77
0.955	0.540	0.59	0.94	0.97	0.56	0.73	0.77
0.96	0.542	0.59	0.94	0.97	0.56	0.73	0.77
0.965	0.545	0.59	0.94	0.97	0.56	0.73	0.77
0.97	0.548	0.59	0.94	0.97	0.56	0.73	0.77
0.975	0.551	0.59	0.94	0.97	0.56	0.73	0.77
0.98	0.554	0.59	0.94	0.97	0.56	0.74	0.77
0.985	0.557	0.59	0.94	0.97	0.56	0.74	0.77
0.99	0.559	0.60	0.94	0.97	0.57	0.74	0.77
0.995	0.562	0.60	0.94	0.97	0.57	0.74	0.77
1	0.565	0.60	0.94	0.97	0.57	0.74	0.77

Table B.5 - Probability values M=5.5

Magnitude		5.5	Constant values from Holzer, et al. (2011)				
MSF		2.21					
a		0.65	0.95	0.98	0.60	0.75	0.78
b		0.30	0.19	0.25	0.24	0.24	0.23
c		-3.78	-3.84	-8.04	-3.23	-4.37	-4.66
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.005	0.002	0.00	0.00	0.00	0.00	0.00	0.00
0.01	0.005	0.00	0.00	0.00	0.00	0.00	0.00
0.015	0.007	0.00	0.00	0.00	0.00	0.00	0.00
0.02	0.009	0.00	0.00	0.00	0.00	0.00	0.00
0.025	0.011	0.00	0.00	0.00	0.00	0.00	0.00
0.03	0.014	0.00	0.00	0.00	0.00	0.00	0.00
0.035	0.016	0.00	0.00	0.00	0.00	0.00	0.00
0.04	0.018	0.00	0.00	0.00	0.00	0.00	0.00
0.045	0.020	0.00	0.00	0.00	0.00	0.00	0.00
0.05	0.023	0.00	0.00	0.00	0.00	0.00	0.00
0.055	0.025	0.00	0.00	0.00	0.00	0.00	0.00
0.06	0.027	0.00	0.00	0.00	0.00	0.00	0.00
0.065	0.029	0.00	0.00	0.00	0.00	0.00	0.00
0.07	0.032	0.00	0.00	0.00	0.00	0.00	0.00
0.075	0.034	0.00	0.00	0.00	0.00	0.00	0.00
0.08	0.036	0.00	0.00	0.00	0.00	0.00	0.00
0.085	0.038	0.00	0.00	0.00	0.00	0.00	0.00
0.09	0.041	0.00	0.00	0.00	0.00	0.00	0.00
0.095	0.043	0.00	0.00	0.00	0.00	0.00	0.00
0.1	0.045	0.00	0.00	0.00	0.00	0.00	0.00
0.105	0.047	0.00	0.00	0.00	0.00	0.00	0.00
0.11	0.050	0.00	0.01	0.00	0.00	0.00	0.00
0.115	0.052	0.00	0.01	0.00	0.00	0.00	0.00
0.12	0.054	0.00	0.01	0.00	0.00	0.00	0.00
0.125	0.057	0.00	0.01	0.00	0.01	0.00	0.00
0.13	0.059	0.00	0.01	0.00	0.01	0.00	0.00
0.135	0.061	0.00	0.01	0.00	0.01	0.00	0.00
0.14	0.063	0.00	0.01	0.00	0.01	0.00	0.00
0.145	0.066	0.00	0.02	0.00	0.01	0.00	0.00
0.15	0.068	0.00	0.02	0.00	0.01	0.00	0.00
0.155	0.070	0.00	0.02	0.00	0.01	0.00	0.00
0.16	0.072	0.00	0.02	0.00	0.01	0.00	0.00
0.165	0.075	0.00	0.03	0.00	0.01	0.00	0.00
0.17	0.077	0.00	0.03	0.00	0.01	0.01	0.00
0.175	0.079	0.00	0.03	0.00	0.02	0.01	0.01
0.18	0.081	0.00	0.04	0.00	0.02	0.01	0.01
0.185	0.084	0.01	0.04	0.00	0.02	0.01	0.01
0.19	0.086	0.01	0.05	0.00	0.02	0.01	0.01
0.195	0.088	0.01	0.05	0.00	0.02	0.01	0.01
0.2	0.090	0.01	0.06	0.00	0.02	0.01	0.01
0.205	0.093	0.01	0.06	0.00	0.03	0.01	0.01
0.21	0.095	0.01	0.07	0.00	0.03	0.01	0.01
0.215	0.097	0.01	0.07	0.00	0.03	0.01	0.01
0.22	0.099	0.01	0.08	0.00	0.03	0.02	0.01

Table B.5 Continued

Magnitude		5.5	Constant values from Holzer, et al. (2011)				
MSF		2.21					
a		0.65	0.95	0.98	0.60	0.75	0.78
b		0.30	0.19	0.25	0.24	0.24	0.23
c		-3.78	-3.84	-8.04	-3.23	-4.37	-4.66
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.225	0.102	0.01	0.09	0.00	0.04	0.02	0.02
0.23	0.104	0.01	0.09	0.00	0.04	0.02	0.02
0.235	0.106	0.01	0.10	0.00	0.04	0.02	0.02
0.24	0.109	0.01	0.11	0.00	0.04	0.02	0.02
0.245	0.111	0.02	0.11	0.00	0.05	0.03	0.02
0.25	0.113	0.02	0.12	0.00	0.05	0.03	0.03
0.255	0.115	0.02	0.13	0.00	0.05	0.03	0.03
0.26	0.118	0.02	0.14	0.00	0.05	0.03	0.03
0.265	0.120	0.02	0.15	0.00	0.06	0.04	0.03
0.27	0.122	0.02	0.16	0.00	0.06	0.04	0.04
0.275	0.124	0.02	0.17	0.00	0.06	0.04	0.04
0.28	0.127	0.02	0.18	0.00	0.07	0.04	0.04
0.285	0.129	0.03	0.19	0.00	0.07	0.05	0.05
0.29	0.131	0.03	0.20	0.00	0.07	0.05	0.05
0.295	0.133	0.03	0.21	0.01	0.08	0.06	0.06
0.3	0.136	0.03	0.22	0.01	0.08	0.06	0.06
0.305	0.138	0.03	0.23	0.01	0.09	0.06	0.06
0.31	0.140	0.04	0.24	0.01	0.09	0.07	0.07
0.315	0.142	0.04	0.25	0.01	0.09	0.07	0.07
0.32	0.145	0.04	0.26	0.01	0.10	0.08	0.08
0.325	0.147	0.04	0.27	0.01	0.10	0.08	0.08
0.33	0.149	0.04	0.29	0.01	0.11	0.09	0.09
0.335	0.151	0.05	0.30	0.02	0.11	0.09	0.10
0.34	0.154	0.05	0.31	0.02	0.12	0.10	0.10
0.345	0.156	0.05	0.32	0.02	0.12	0.10	0.11
0.35	0.158	0.05	0.33	0.02	0.12	0.11	0.11
0.355	0.161	0.06	0.35	0.02	0.13	0.11	0.12
0.36	0.163	0.06	0.36	0.03	0.13	0.12	0.13
0.365	0.165	0.06	0.37	0.03	0.14	0.13	0.13
0.37	0.167	0.07	0.38	0.03	0.14	0.13	0.14
0.375	0.170	0.07	0.39	0.04	0.15	0.14	0.15
0.38	0.172	0.07	0.40	0.04	0.15	0.15	0.16
0.385	0.174	0.08	0.42	0.05	0.16	0.15	0.16
0.39	0.176	0.08	0.43	0.05	0.16	0.16	0.17
0.395	0.179	0.08	0.44	0.06	0.17	0.17	0.18
0.4	0.181	0.09	0.45	0.06	0.17	0.17	0.19
0.405	0.183	0.09	0.46	0.07	0.18	0.18	0.20
0.41	0.185	0.09	0.47	0.07	0.18	0.19	0.21
0.415	0.188	0.10	0.48	0.08	0.19	0.20	0.21
0.42	0.190	0.10	0.50	0.09	0.19	0.20	0.22
0.425	0.192	0.10	0.51	0.10	0.20	0.21	0.23
0.43	0.194	0.11	0.52	0.10	0.20	0.22	0.24
0.435	0.197	0.11	0.53	0.11	0.21	0.23	0.25
0.44	0.199	0.12	0.54	0.12	0.21	0.24	0.26

Table B.5 Continued

Magnitude		5.5	Constant values from Holzer, et al. (2011)				
MSF		2.21					
a		0.65	0.95	0.98	0.60	0.75	0.78
b		0.30	0.19	0.25	0.24	0.24	0.23
c		-3.78	-3.84	-8.04	-3.23	-4.37	-4.66
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.445	0.201	0.12	0.55	0.13	0.22	0.24	0.27
0.45	0.203	0.12	0.56	0.14	0.22	0.25	0.28
0.455	0.206	0.13	0.57	0.16	0.23	0.26	0.29
0.46	0.208	0.13	0.58	0.17	0.23	0.27	0.30
0.465	0.210	0.14	0.59	0.18	0.24	0.28	0.30
0.47	0.213	0.14	0.60	0.19	0.24	0.28	0.31
0.475	0.215	0.15	0.61	0.21	0.25	0.29	0.32
0.48	0.217	0.15	0.61	0.22	0.25	0.30	0.33
0.485	0.219	0.16	0.62	0.23	0.26	0.31	0.34
0.49	0.222	0.16	0.63	0.25	0.26	0.32	0.35
0.495	0.224	0.16	0.64	0.27	0.27	0.33	0.36
0.5	0.226	0.17	0.65	0.28	0.27	0.33	0.37
0.505	0.228	0.17	0.66	0.30	0.28	0.34	0.38
0.51	0.231	0.18	0.66	0.31	0.28	0.35	0.39
0.515	0.233	0.18	0.67	0.33	0.29	0.36	0.40
0.52	0.235	0.19	0.68	0.35	0.29	0.37	0.41
0.525	0.237	0.19	0.69	0.37	0.30	0.37	0.41
0.53	0.240	0.20	0.69	0.38	0.30	0.38	0.42
0.535	0.242	0.20	0.70	0.40	0.31	0.39	0.43
0.54	0.244	0.21	0.71	0.42	0.31	0.40	0.44
0.545	0.246	0.21	0.71	0.44	0.31	0.40	0.45
0.55	0.249	0.22	0.72	0.45	0.32	0.41	0.46
0.555	0.251	0.22	0.72	0.47	0.32	0.42	0.46
0.56	0.253	0.23	0.73	0.49	0.33	0.43	0.47
0.565	0.255	0.23	0.74	0.51	0.33	0.43	0.48
0.57	0.258	0.24	0.74	0.52	0.34	0.44	0.49
0.575	0.260	0.24	0.75	0.54	0.34	0.45	0.49
0.58	0.262	0.25	0.75	0.56	0.34	0.45	0.50
0.585	0.265	0.25	0.76	0.57	0.35	0.46	0.51
0.59	0.267	0.26	0.76	0.59	0.35	0.47	0.52
0.595	0.269	0.26	0.77	0.61	0.36	0.47	0.52
0.6	0.271	0.27	0.77	0.62	0.36	0.48	0.53
0.605	0.274	0.27	0.78	0.64	0.36	0.49	0.54
0.61	0.276	0.28	0.78	0.65	0.37	0.49	0.54
0.615	0.278	0.28	0.79	0.67	0.37	0.50	0.55
0.62	0.280	0.29	0.79	0.68	0.38	0.51	0.56
0.625	0.283	0.29	0.79	0.69	0.38	0.51	0.56
0.63	0.285	0.30	0.80	0.70	0.38	0.52	0.57
0.635	0.287	0.30	0.80	0.72	0.39	0.52	0.57
0.64	0.289	0.31	0.81	0.73	0.39	0.53	0.58
0.645	0.292	0.31	0.81	0.74	0.39	0.53	0.58
0.65	0.294	0.32	0.81	0.75	0.40	0.54	0.59
0.655	0.296	0.32	0.82	0.76	0.40	0.54	0.59
0.66	0.298	0.33	0.82	0.77	0.40	0.55	0.60

Table B.5 Continued

Magnitude		5.5	Constant values from Holzer, et al. (2011)				
MSF		2.21					
a		0.65	0.95	0.98	0.60	0.75	0.78
b		0.30	0.19	0.25	0.24	0.24	0.23
c		-3.78	-3.84	-8.04	-3.23	-4.37	-4.66
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.665	0.301	0.33	0.82	0.78	0.41	0.55	0.60
0.67	0.303	0.34	0.83	0.79	0.41	0.56	0.61
0.675	0.305	0.34	0.83	0.80	0.41	0.56	0.61
0.68	0.307	0.34	0.83	0.81	0.42	0.57	0.62
0.685	0.310	0.35	0.84	0.82	0.42	0.57	0.62
0.69	0.312	0.35	0.84	0.82	0.42	0.58	0.63
0.695	0.314	0.36	0.84	0.83	0.42	0.58	0.63
0.7	0.317	0.36	0.84	0.84	0.43	0.58	0.64
0.705	0.319	0.37	0.85	0.84	0.43	0.59	0.64
0.71	0.321	0.37	0.85	0.85	0.43	0.59	0.64
0.715	0.323	0.37	0.85	0.86	0.44	0.60	0.65
0.72	0.326	0.38	0.85	0.86	0.44	0.60	0.65
0.725	0.328	0.38	0.86	0.87	0.44	0.60	0.65
0.73	0.330	0.39	0.86	0.87	0.44	0.61	0.66
0.735	0.332	0.39	0.86	0.88	0.45	0.61	0.66
0.74	0.335	0.40	0.86	0.88	0.45	0.61	0.66
0.745	0.337	0.40	0.87	0.89	0.45	0.62	0.67
0.75	0.339	0.40	0.87	0.89	0.45	0.62	0.67
0.755	0.341	0.41	0.87	0.90	0.46	0.62	0.67
0.76	0.344	0.41	0.87	0.90	0.46	0.63	0.68
0.765	0.346	0.41	0.87	0.90	0.46	0.63	0.68
0.77	0.348	0.42	0.88	0.91	0.46	0.63	0.68
0.775	0.350	0.42	0.88	0.91	0.47	0.64	0.68
0.78	0.353	0.43	0.88	0.91	0.47	0.64	0.69
0.785	0.355	0.43	0.88	0.92	0.47	0.64	0.69
0.79	0.357	0.43	0.88	0.92	0.47	0.64	0.69
0.795	0.359	0.44	0.88	0.92	0.47	0.65	0.69
0.8	0.362	0.44	0.89	0.92	0.48	0.65	0.70
0.805	0.364	0.44	0.89	0.93	0.48	0.65	0.70
0.81	0.366	0.45	0.89	0.93	0.48	0.65	0.70
0.815	0.369	0.45	0.89	0.93	0.48	0.66	0.70
0.82	0.371	0.45	0.89	0.93	0.48	0.66	0.70
0.825	0.373	0.46	0.89	0.93	0.49	0.66	0.71
0.83	0.375	0.46	0.89	0.94	0.49	0.66	0.71
0.835	0.378	0.46	0.90	0.94	0.49	0.66	0.71
0.84	0.380	0.46	0.90	0.94	0.49	0.67	0.71
0.845	0.382	0.47	0.90	0.94	0.49	0.67	0.71
0.85	0.384	0.47	0.90	0.94	0.49	0.67	0.72
0.855	0.387	0.47	0.90	0.94	0.50	0.67	0.72
0.86	0.389	0.48	0.90	0.95	0.50	0.67	0.72
0.865	0.391	0.48	0.90	0.95	0.50	0.68	0.72
0.87	0.393	0.48	0.90	0.95	0.50	0.68	0.72
0.875	0.396	0.48	0.90	0.95	0.50	0.68	0.72
0.88	0.398	0.49	0.91	0.95	0.50	0.68	0.72

Table B.5 Continued

Magnitude		5.5	Constant values from Holzer, et al. (2011)				
MSF		2.21					
a		0.65	0.95	0.98	0.60	0.75	0.78
b		0.30	0.19	0.25	0.24	0.24	0.23
c		-3.78	-3.84	-8.04	-3.23	-4.37	-4.66
		Probability					
PGA (g)	PGA/MSF	Alluvial Fan	Beach Ridge	Delta	Floodplain	Lagoonal	Fill
0.885	0.400	0.49	0.91	0.95	0.51	0.68	0.73
0.89	0.402	0.49	0.91	0.95	0.51	0.68	0.73
0.895	0.405	0.49	0.91	0.95	0.51	0.69	0.73
0.9	0.407	0.50	0.91	0.96	0.51	0.69	0.73
0.905	0.409	0.50	0.91	0.96	0.51	0.69	0.73
0.91	0.412	0.50	0.91	0.96	0.51	0.69	0.73
0.915	0.414	0.50	0.91	0.96	0.51	0.69	0.73
0.92	0.416	0.51	0.91	0.96	0.52	0.69	0.73
0.925	0.418	0.51	0.91	0.96	0.52	0.69	0.74
0.93	0.421	0.51	0.91	0.96	0.52	0.70	0.74
0.935	0.423	0.51	0.92	0.96	0.52	0.70	0.74
0.94	0.425	0.52	0.92	0.96	0.52	0.70	0.74
0.945	0.427	0.52	0.92	0.96	0.52	0.70	0.74
0.95	0.430	0.52	0.92	0.96	0.52	0.70	0.74
0.955	0.432	0.52	0.92	0.96	0.52	0.70	0.74
0.96	0.434	0.52	0.92	0.96	0.52	0.70	0.74
0.965	0.436	0.53	0.92	0.96	0.53	0.70	0.74
0.97	0.439	0.53	0.92	0.96	0.53	0.70	0.74
0.975	0.441	0.53	0.92	0.96	0.53	0.71	0.75
0.98	0.443	0.53	0.92	0.97	0.53	0.71	0.75
0.985	0.445	0.53	0.92	0.97	0.53	0.71	0.75
0.99	0.448	0.54	0.92	0.97	0.53	0.71	0.75
0.995	0.450	0.54	0.92	0.97	0.53	0.71	0.75
1	0.452	0.54	0.92	0.97	0.53	0.71	0.75

Appendix C: Probability Curves

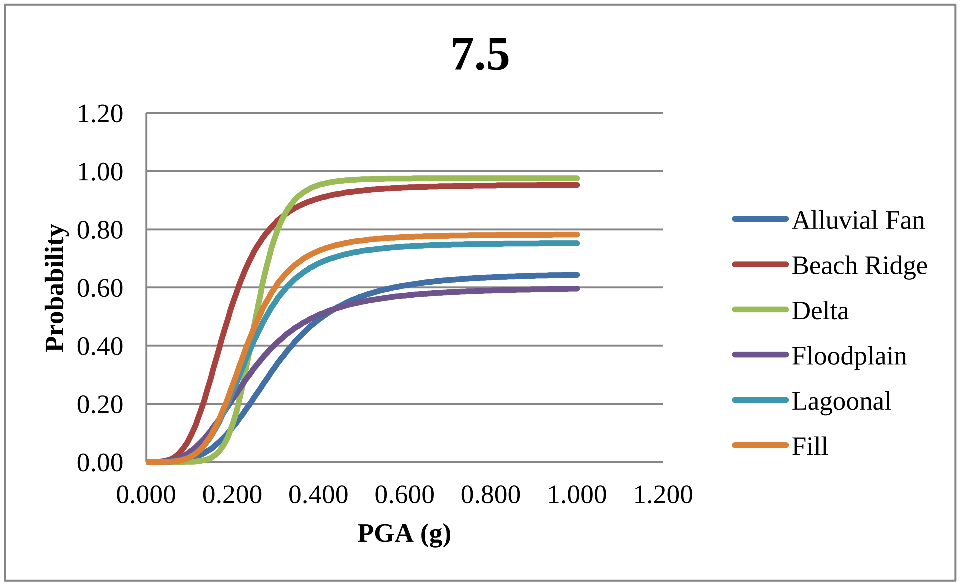

Figure C.1 - Probability curves M=7.5

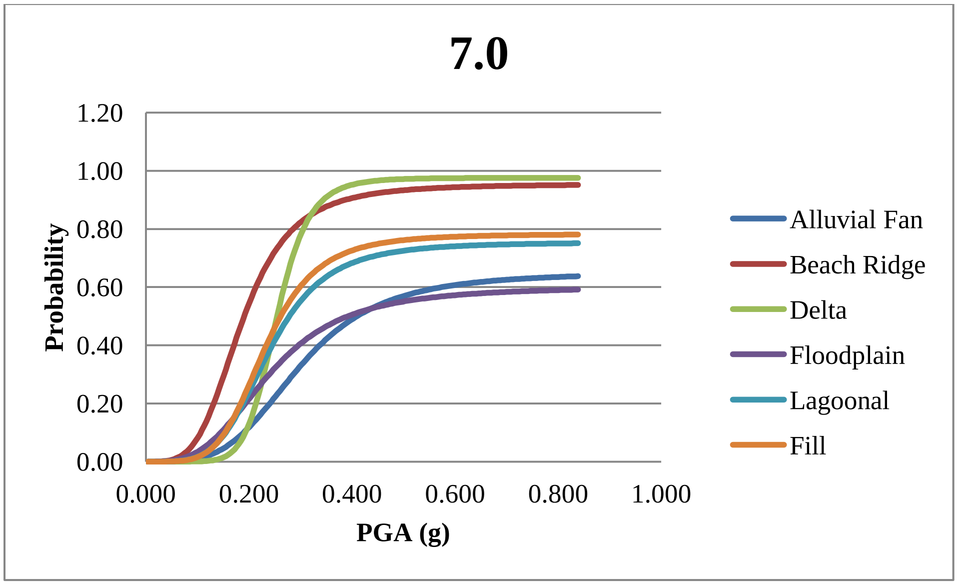

Figure C.2 - Probability curves M=7.0

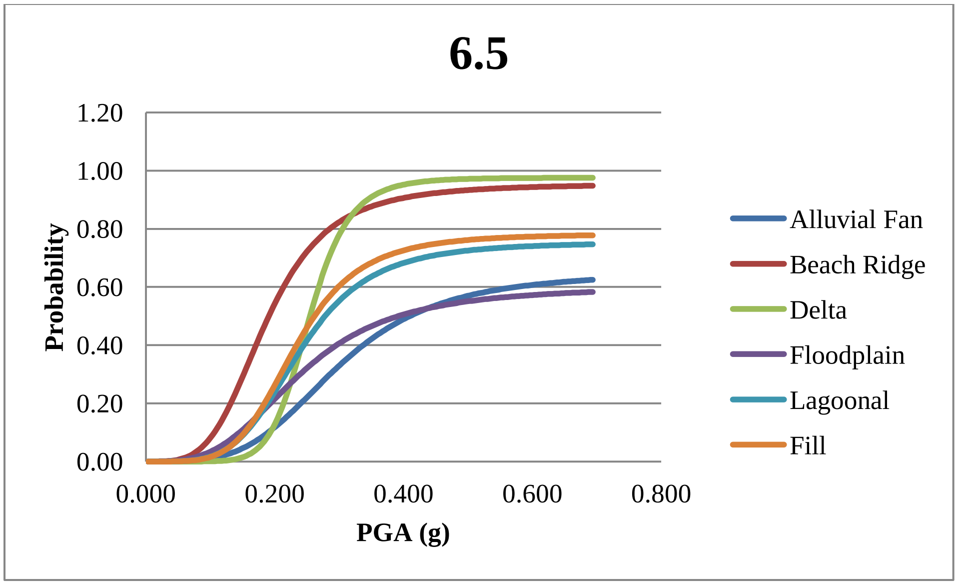

Figure C.3 - Probability curves M=6.5

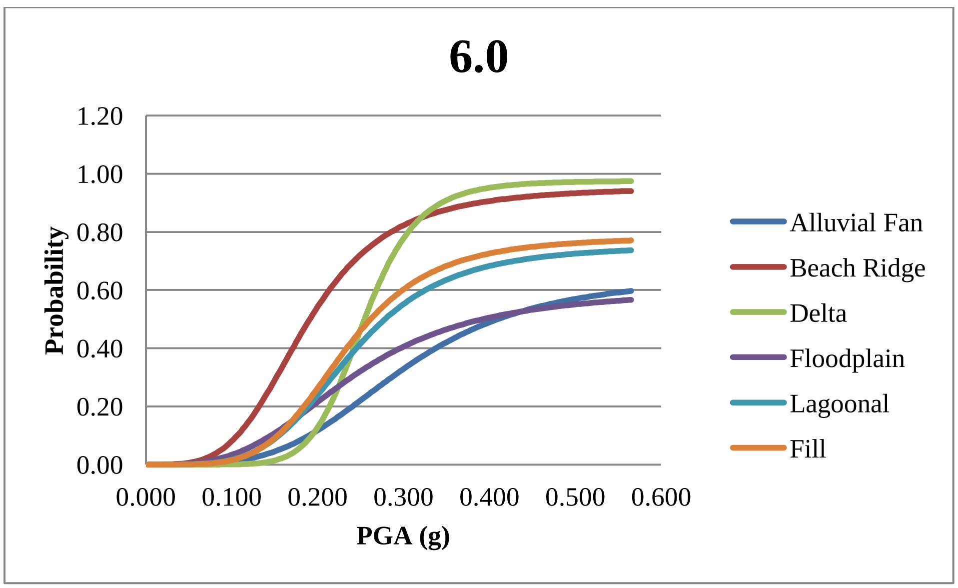

Figure C.4 - Probability curves M=6.0

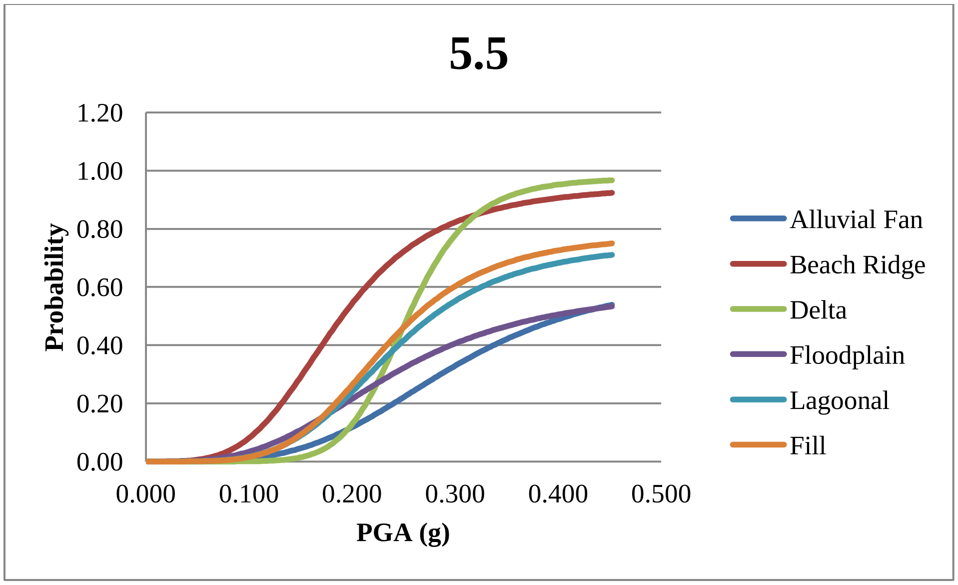

Figure C.5 - Probability curves M=5.5

RESOURCES

Adams, W. D. (1997). *13 Proposed Revisions to the National Building Code of Jamaica.* Mona, Kingston, Jamaica: The University of the West Indies.

National Emergency Management Agency. (1994). Trinidad Hazard & Response Map. Port of Spain, Trinidad and Tobago: Government of The Republic of Trinidad & Tobago.

Baise, L. G., Higgins, R. B., & Brankman, C. M. (2006). Liquefaction Hazard Mapping - Statistical and Spatial Characterization of Susceptible Units. *Journal of Geotechnical and Geoenvironmental Engineering*, 705-715.

Beard, T., & Claire, A. (2012). Sustainable Cities: the Case of Greater Port of Spain. *48th ISOCARP Conference.* Perm, Russia: ISOCARP.

Beroya, M., & Aydin, A. (2010). A new approach to liquefaction hazard zonation: Application to Laoag City, Northern Philippines. *Soil Dynamics and Earthquake Engineering*, 1338-1351.

Beroya, M., Aydin, A., Tiglao, R., & Lasala, M. (2009). Use of microtremor in liquefaction hazard mapping. *Engineering Geology*, 140-153.

Bozzoni, F., Corigliano, M., Lai, C. G., Salazar, W., Scandella, L., Zuccolo, E., . . . Robertson, R. (2011). Probabilistic seismic hazard assessment at the eastern Caribbean Islands. *Bulletin of the Seismological Society of America*, 2499-2521.

Bray, J. D., & Sancio, R. B. (2006). 2006. *Journal of Geotechnical and Geoenvironmental Engineering*, 1165-1177.

Brown, C. (1965). *Land Capability Survey of Trinidad and Tobago.* Port of Spain: Caribbean Printers Limited.

Brown, C. W. (1907, May). The Jamaica Earthquake. *The Popular Science Monthly*, pp. 385-403.

Brown, L. (2010). Development of a Seismic Hazard Map for Jamaica. Mona, Jamaica: Earthquake Unit, University of the West Indies.

Calais, E., Bethoux, N., & Mercier, B. (1992). From transcurrent faulting to frontal subduction: A seismotectonic study of the northern Caribbean plate boundary from Cuba to Puerto Rico. *Tectonics*, 114-123.

Calais, E. (2013, March 28). *The January 12, 2010 Haiti Earthquake.* Retrieved from Context http://web.ics.purdue.edu/~ecalais/haiti

DeMets, C., & Wiggins-Grandison, M. (2007). Deformation of Jamaica and motion of the Gonave microplate from GPS and seismic data. *Geophysical Journal International*, 362-378.

Elliot, A. (1892, April). The Great Earthquake of Port Royal. *Popular Science*, pp. 774-784.

Escalona, A., & Mann, P. (2011). Tectonics, basin subsidence mechanisms, and paleogography of the Caribbean-South American plate boundary zone. *Marine and Petroleum Geology*, 8-39.

Faccioli, E., & Calvi, G. M. (2003). *Model Building Code For Earthquakes.* Port of Spain, Trinidad and Tobago: Association of Caribbean States.

Federal Emergency Management Agency. (2003). *Developing the Mitigation Plan.* Washington, D.C.: FEMA.

Flood Susceptibility Map Trinidad. (2011, March). Tacarigua, Trinidad and Tobago: Office of Disaster Preparedness and Management.

Food and Agriculture Organization of the United Nations. (2003, January). The Digital Soil Map of the World Version 3.6. Rome, Italy: FAO/UNESCO 1995.

Graham, O. (2010). *Seismicisty of Trinidad and Tobago.* St. Augustine, Trinidad and Tobago: University of the West Indies Seismic Resarch Center.

Green, R. A., Olson, S. M., Cox, B. R., Rix, G. J., Rathje, E., Bachhuber, J., . . . Martin, N. (2011). Geotechnical Aspects of Failures at Port-au-Prince Seaport during the 12 January 2010 Haiti Earthquake. *Earthquake Spectra*, S43-S65.

Hengesh, J. V., & Bachhuber, J. L. (2005). Liquefaction susceptibility zonation map of San Juan, Puerto Rico. *Geologic Society of America Special Paper 385*, 249-262.

Holzer, T. L., Bennet, M. J., Noce, T. E., & Tinsley, J. C. (2005). Shear-Wave Velocity of Surficial Geologic Sediments in Northern California: Statitical Distributions and Depth Dependence. *Earthquake Spectra*, 161-177.

Holzer, T. L., Noce, T. E., & Bennett, M. J. (2011). Liquefaction Probability Curves for Surficial Geologic Deposits. *Environmental and Engineering Geoscience*, 1-21.

Hornbach, et al. (2011). Assessing geohazards near Kingston, Jamaica: Initial results from chirp profiling. *The Leading Edge*, 410-413.

Kayen, R. E., & Mitchell, J. K. (1997). Assessment of Liquefaction Potential during Earthquakes by Arias Intensity. *Journal of Geotechnical and Geoenvironmental Engineering*, 1162-1174.

Kramer, S. L., & Mayfield, R. T. (2007). Return Period of Soil Liquefaction. *Journal of Geotechnical and Geoenvironmental Engineering*, 802-813.

Larsen, M. (2008). Rainfall-triggered landslides, anthropogenic hazards, and mitigation strategies. *Advances in Geosciences*, 147-153.

Latchman, J. L. (2010). Eastern Caribbean Earthquakes - Past Present and Future Implications for Trinidad and Tobago. St. Augustine, Trinidad and Tobago: The University of the West Indies.

Liao, T., & Mayne, P. (2002). Evaluation of Dynamic Soil Properties and Liquefaction Potential by Seismic Piezocone Tests. *Proceedings of the International Conference on Advances and New Challenges in Earthquake Engineering, Hong Kong Volume*, 115-122.

Lindell, M. K., & Prater, C. S. (2003). Assessing Community Impacts of Natural Disasters. *Natural Hazards Review*, 176-185.

Lyew-Ayee Jr., P., Francis, C., & Ahmad, R. (2009). *Introducing: The Natural Hazards Atlas for Jamaica.* Mona, Jamaica: Mona Geoinformatics Institute.

Macari, E. J., & Hoyos, L. R. (2005). Earthquake-induced liquefaction potential in wester Puerto Rico using GIS technology. *Geological Society of America Special Paper 385*, 277-287.

Macari, E., & Hoyos, L. (2005). Earthquake-induced liquefaction potential in wester Puerto Rico usign GIS technology. *Special Papers-Geological Society of America*, 277-287.

McFarlane, N., Lyew-Ayes, D., & Wright, R. (1977). Jamaica - Geology. Kingston, Jamaica: Mines and Geology Division, Ministry of Mining & Natural Resources.

McGuire, R., & Arabasz, W. (1990). An Introduction to Probabilisitic Seismic Hazard Analysis. In S. H. Ward, *Geotechncial and Environmental Geophysics: Volume 1: Review and Tutorial* (pp. 333-354). Society of Exploration Geophysicists.

Miller, N. K., Waite, L., & Harlan, A. E. (2001). *Water Resources Assessment of Jamaica.* US Army Corps of Engineers.

Mocquet, A. (2007). Analysis and interpretation of the October 21, 1766 earthquake in the Southeastern Caribbean. *Journal of Seismology*, 381-403.

Olson, S. M., Green, R. A., Lasley, S., Martin, N., Cox, B. R., Rathje, E., . . . French, J. (2011). Documenting Liquefaction and Lateral Spreading Triggered by the 12 January 2010 Haiti Earthquake. *Earthquake Spectra*, S93-S116.

Opadeyi, J., & Thongs, G. (2011, March). Flood Susceptibility Map: Trinidad. Tacarigua, Trindidad and Tobago: Office of Disaster Preparedness and Managment.

Panagiotopoulos, D. (1995). Long-term earthquake prediction in Central America and the Caribbean Sea based on the time- and magnitude- predictable model. *Bulletin of the Seismological Society of America*, 1190-1201.

Pollitz, F., & Dixon, T. (1998). GPS measurements across the northern Caribbean plate boundary zone: Impact of postseismic relaxation following historic earthquakes. *Geophysical Research Letters*, 2233-2236.

Seed, H. (1987). Design Problems in Soil Liquefaction. *Journal of Geotechnical Engineering*, 827-845.

Seed, H. B., Tokimatsu, K., Harder, L., & Chung, R. (1985). Influence of SPT Procedures in Soil Liquefaction Resistance Evaluations. *Journal of Geotechnical Engineering*, 1425-1445.

Shedlock, K. M. (1999). Sesimic Hazard Map of North and Central America and the Caribbean. *Annali di Geofisica*, 977-997.

Shepherd, J., Tanner, J., McQueen, C., & Lynch, L. L. (1997). *Final Report - Seismic Hazard in Latin America and the Caribbean Seismic Hazard Maps for the Caribbean.* Ottawa, Canada: International Development and Research Centre.

Sumer, B. M., Ansal, A., Cetin, K. O., Damgaard, J., Gunbak, A. R., Hansen, N.-E. O., . . . Zen, K. (2007). Earthquake-Induced Liquefaction around Marine Structures. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 55-82.

The Cropper Foundation. (2005, October). Northern Range Assessment. St. Augustine, Trinidad and Tobago: The Cropper Foundation.

Toprak, S., & Holzer, T. L. (2003). Liquefaction Potential Index: Field Assessment. *Journal of Geotechnical and Geoenvironmental Engineering*, 315-322.

Tortello, R. (2013, March 12). *1692: Earthquake of Port Royal*. Retrieved from Pieces of the Past: http://jamaica-gleaner.com/pages/history/story001.html

Tortello, R. (2013, March 11). *Disaster - The Earthquake of 1907*. Retrieved from Pieces of the Past: http://jamaica-gleaner.com/pages/history/story0017.html

Tsukamoto, Y., & Ishihara, K. (2010). Analysis on Settlement of Soil Deposits Following Liquefaction During Earthquakes. *Soils and Foundation*, 399-411.

Weber, J. C., Dixon, T. H., DeMets, C., Ambeh, W. B., Jansma, P., Mattioli, G., . . . Perez, O. (2012). GPS estimate of relative motion between the Caribbean and South American plates, and geologic implications for Trinidad and Venezuela. *Geology*, 75-78.

Werner, S., McCullough, N., Bruin, W., Augustine, A., Rix, G., Crowder, B., & Tomblin, J. (2011). Seismic Performance of Portde Port-au-Prince during the Haiti Earthquake and Post-Earthquake Restoration of Cargo Throughput. *Earthquake Spectra*, S387-S410.

Wiggins-Grandison, M., Nishenko, S., McCann, B., & Honeycutt, M. (2013, March 12). *Final Report: Kingston Metropolitan Seismic Hazard Assessment*. Retrieved from Caribbean Disaster Mitigation Project: http://www.oas.org/cdmp/document/kma/seismic/kma1.htm

Youd, T. L., & Perkins, D. M. (1978). Mapping Liquefaction-Induced Ground Failure Potential. *Journal of the Geotechnical Engineering Division*, 443-446.

Youd, T. L., & Perkins, D. M. (1987). Mapping of Liquefaction Severity Index. *Journal of Geotechnical Engineering*, 1374-1392.

Youd, T., Idriss, I., Andrus, R., Arango, I., Castro, G., Christian, J., . . . et al. (2001). Liquefation Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils. *Journal of Geotechnical and Geoenvironmental Engineering*, 817-833.